KWJ ENGINEERING INC | INNOVATIVE SOLUTIONS FOR GAS DETECTION

SPEC SENSORS

Gas Sensors for the Internet of Things

MANUFACTURING NANO-ENABLED SENSORS – LAB TO MARKET

Joseph R. Stetter, Ph.D, President and CTO
KWJ Enginering Inc and SPEC-sensors LLC
8430 Central Ave., suite 2C, Newark, CA 94560 USA

Nanosensors Manufacturing: Finding Better Paths to Products

June 13-14, 2017, at the National Science Foundation in Arlington, VA

USPs 8,105,539; 6,808,618; 7,911,010; 8,884,382; 9,213,016; and pending PCT, China, US applications for Sensors, Systems, Packaging, and AI.

KWJ Engineering Inc.and Spec Sensors LLC
Contact: E. F. Stetter VP/GM and CFO.
Kwjengineering.com or spec-sensors.com
510-405-5911

KWJ Engineering Inc.

- Innovative Solutions in Gas Detection since 1993
  - Founded by Ken Johnson, formerly of GasTech (sold to Thermo Electron)
  - Leverage buyout by Dr. Joseph R. Stetter in 2007 [merged TTI, Inc.; TRI was sold to TSI, 1993]
  - Acquisition of ECO sensors [L.Killham company ozone safety equipment] in 2008.
  - Senior staff with 150 years combined experience in sensing/detection/instruments.
  - Longstanding products/Engineering combined with cutting edge sensor technology.

- Our Vision: Improve human health and safety, security, and environments by providing the next generation of advanced/quality detection products.
  - Smaller, lower power, less expensive, and ever-more-capable sensing platforms.
  - Increased situational awareness in industrial, medical, and consumer markets.

- Competencies: Industry Leaders in advanced gas sensing technologies and custom solutions for chemical sensing, monitoring, and detection.
  - Growth from 10 employees in 2007 to >30 today.

- Products and Services – Distributed, OEM, Custom and R&D Products.
  - Printed Electronics and MEMS for sensors and sensor platforms.
  - Integration into sensing systems and customer solutions sold worldwide.

- ***SPEC SENSORS = spin off of technology to manufacture component sensors!***

Facilities and Capabilities
Sensor Design→Fabricate→Test

Design

Post Processing

Custom Metrology

- **Advanced Facilities, Technology, Personnel**
  - [Silicon Valley, Santa Fe, Chicago, Denver, Atlanta, Indiana]
    - >9,000 sq ft R&D, Engineering/Manufacturing
    - Clean Room, Test and Environmental Chambers
    - Sensor manufacture, measurement, and test systems
    - **Design, Prototype, Manufacture,Test**-METROLOGY
    - Engineers with >150 yrs combined sensor experience

- **Broad based collaborations and funding.**
  - World Class Collaborators include UC Berkeley (BSAC), Georgia Tech, Stanford Research Institute, U. of Washington, IIT, Oakland University, Wisconsin Lutheran College, private companies, strategic partners, & others
  - Funding from: NSF, NASA, NIH, DOD, DOE, GTI, USA, EPA, and Private/Strategic Partners

- ***Work with others through contract, PO, OEM and collaborative agreements, partnerships, licensing***.

KWJ ENGINEERING INC INNOVATIVE SOLUTIONS FOR GAS DETECTION

SPECSENSORS

Product Lines – KWJ

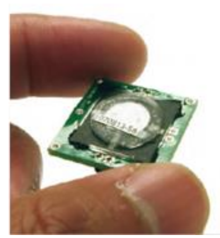
- Eco Sensors – the low cost leader in ozone instruments
  - Broad application for industrial ozone, diverse sensor technology, ambient and dissolved ozone
  - Worldwide distribution --- IoT products; wearables; smart cities!

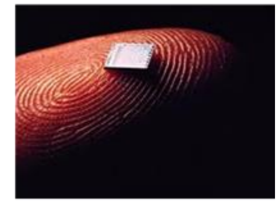
- KWJ In-line OEM
  - CSA Approved 10ppm Alarm for Supplied Breathing Air
  - Low pressure cylinder alarms
  - Pipeline leak detectors

- KWJ Pocket CO
  - Wearable CO monitor
  - High performance in a small, convenient package

- KWJ-WSN
  - Wireless gas sensors for commercial/light industrial, residential
  - Low cost and easy to set up. Long battery life.

SPECSENSORS *Overview*





- Founded in 2012 to launch the world's smallest, lowest cost, high performance electrochemical gas sensors
- SPEC Sensors are ultra-low power, ideal for long life battery powered or energy harvested applications
- UL 2034 (& ETL) Recognized Carbon Monoxide Sensor

KWJ – SPEC Intellectual Property

- SPEC Sensors LLC has a patent portfolio for Printed and MEMS sensors.
- SPEC and MEMS sensors have Proprietary Advantages
  - Reduced Size, shape, power
  - High Activity Nano-catalysts
  - New Materials, inks, composites
  - Space-age Structures and designs.
  - Smart operating algorithms
  - Performance, applications engineering
    - Breath for diagnostics and health.
    - Severe environments.
    - Safety and Environmental Monitoring.
    - IoT, wearables, fixed site infrastructure.

USPs 8,105,539; 6,808,618; 7,911,010; 8,884,382; 9,213,016; and pending PCT, China, US applications for Sensors, Systems,Packaging, and AI.

- **Disruptive Requirements:**
- **Extremely small**
- **High Performance**
- **Ultra low power – u-watts**
- **Inexpensive ownership**
- **Reliable – Long life**
- **Low/No Maintenance**
- **Hundreds of millions of units**

- **[KWJ SENSOR GOALS!!!]**

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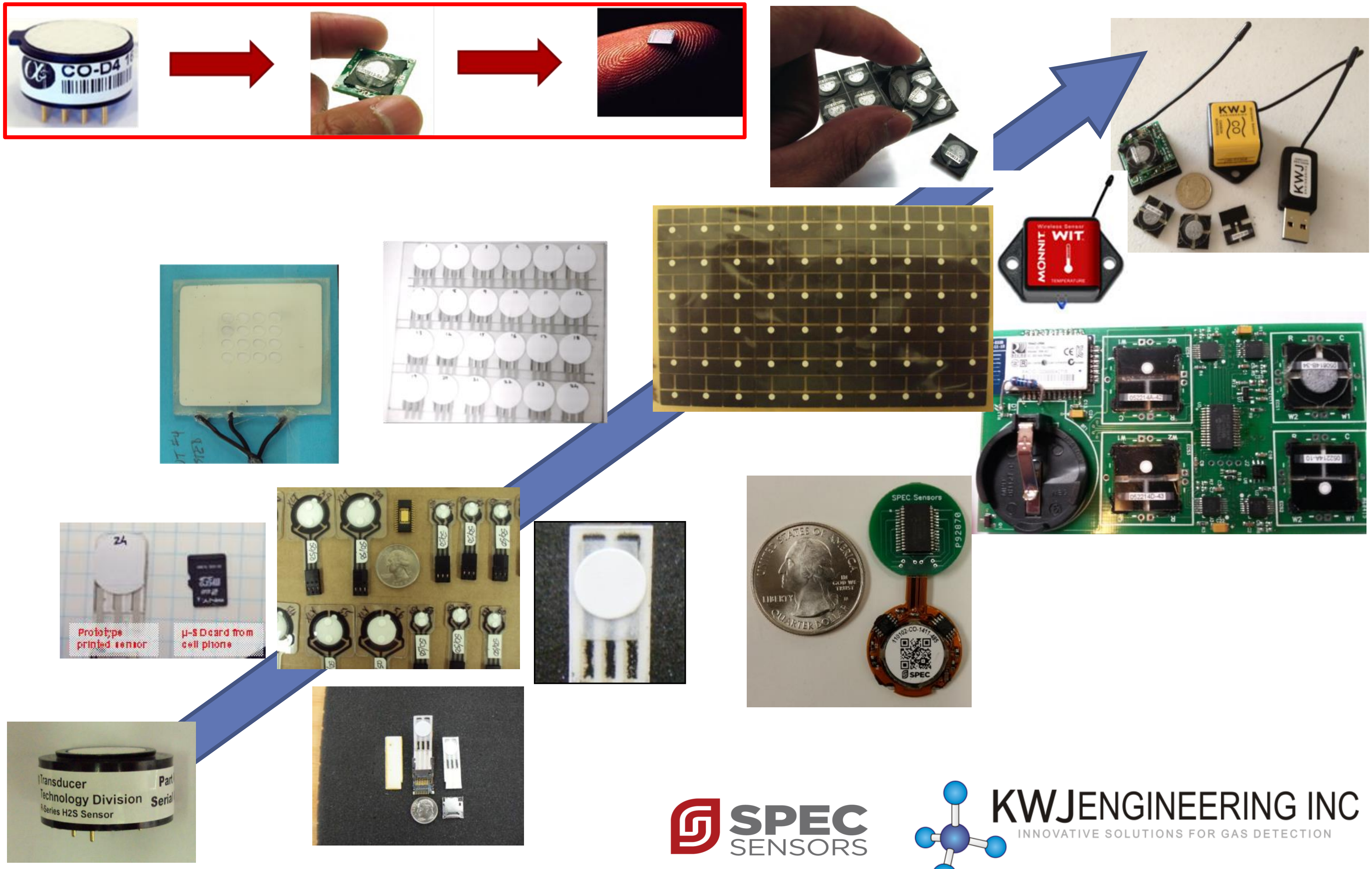
SPECSENSORS

Amperometric Gas Sensor Evolution



SPEC SENSORS

KWJ ENGINEERING INC
INNOVATIVE SOLUTIONS FOR GAS DETECTION

Opportunity – Vision - Execution

$S^5 \rightarrow S^5$

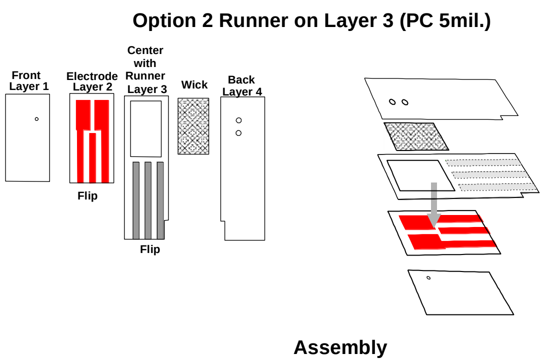
NEW design, materials, processes!

KWJ ENGINEERING INC — INNOVATIVE SOLUTIONS FOR GAS DETECTION

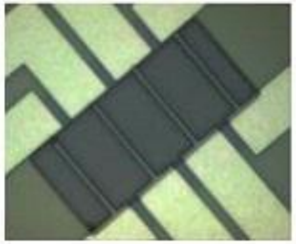
SPECSENSORS

Intellectual Property

- SPEC Sensors owns all IP related to Printed (2) Electrochemical Gas Sensors and MEMS NanoTCD
- Printed sensor claims include geometry/size, inks, materials, construction, packaging
  - Applications and provisionals filed
  - Design and Process (new custom fab!)



- MEMS Patents Issued (3)
  - Claims include size, low power operation, smart operating protocols and algorithms
- in-progress applications (>10)

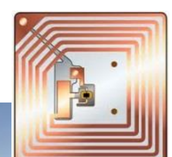


Situational Awareness Changes the Game

Explosion of innovation

Smartphone integration

Disruptive technology



Disruptive Requirements:

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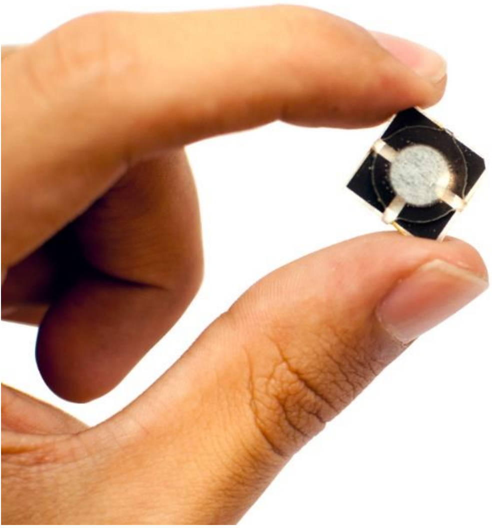
[KWJ SENSOR GOALS!!!]



PRODUCTION SCALE MANUFACTURING OF NANO-ENABLED SENSORS – LAB TO MARKET

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SPEC SENSORS, LLC

Gas Sensors for the Internet of Things

Nanosensors Manufacturing: Finding Better Paths to Products

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Outline - storyboard

- Why worry about air quality?
- WHAT is a sensor? A Chem-Bio sensor? A gas sensor?
- Gas sensors and how to approach the world of sensors
  - Classes, technologies, platforms, arrays and multidimensional "measurements"
    - Spectroelectrochem, piezoelectrochem, TCD-SMOx, and why is chemistry so complex.
- Approach sensor design paradigm
  - Depends on goals – research paper vs comsumer product
  - Paths = MEMS, CMOS, flex hybrid, …
- Manufacturing challenges
  - high V, social impact, accelerate to payoff.
- PATHS – CASE STUDIES – opportunities for Flex Technology
  - Disposable printed instruments
  - Integrated electronics and sensors
  - Major challenges
- MAJOR CHALLENGES: materials, structures; methods.

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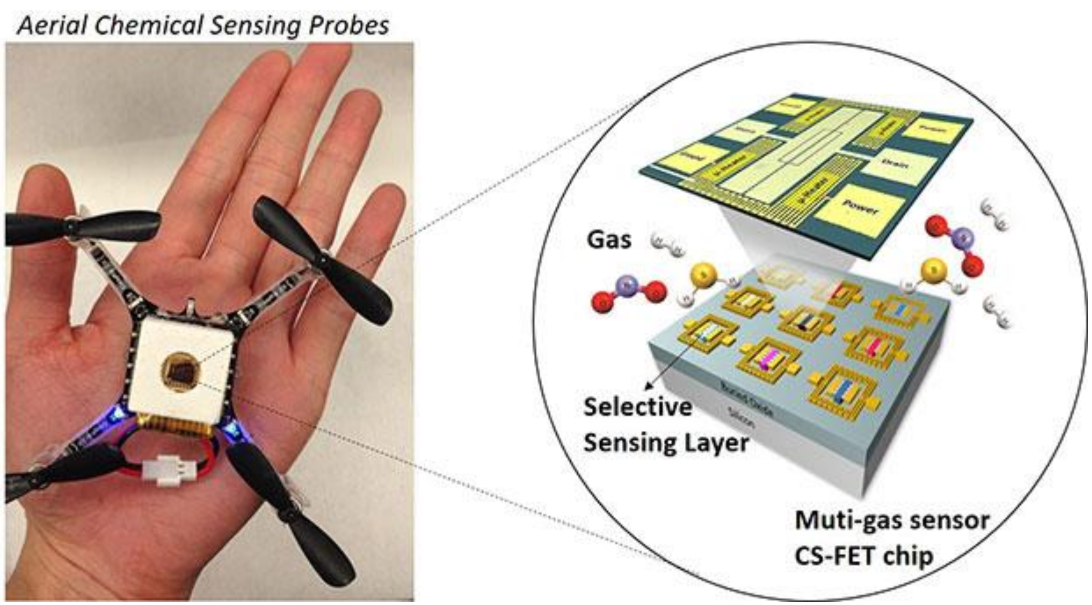
SPECSENSORS

NANOSENSORS – A STORY

1] Explaining how to make a fab for sensors and get to a successful factory and business is difficult on many levels.
2] Simply reporting a series of decisions I made in an extremely interdisciplinary and multifunctional environment is inadequate.
3] The boundary conditions for decisions are unique: influences are simultaneously financial, temporal, market/sales, and technical!



Nanochip Gas Sensors Promise Personal Air Quality Monitors in our Pockets
By DEXTER JOHNSON
Posted 24 Mar 2017 | 18:00 GMT

Mar24, 2017, ieee, spectrum

KWJ and SPEC inside "pregnancy protect" by Intel-Grameen COEL bracelet 2017

Major Manufacturing Challenges – a view

- The problems of the electronics and sensor device industry are rarely associated with chemistry but the amount of chemistry in a product is enormous!
- The vast majority is upstream to the fab in materials.
- Success is often dependent on materials choices and when and where to drive upstream chemistry is critical.
- Lack of chemistry and chemical engineering downstream is cause for great concern
- BUT, mechanical engineers build products and tooling!
- A proactive approach to combine disciplines is crucial.
- Decisions about unit operations and fab integration is a full time job.
- Every team is different in many ways.

Sensor Challenges - where to start!

Explorers and Farmers: and when to think like either or both!
Important influences: provide support + reduce risk & paperwork [INFRASTRUCTURE for progress]

- State the question?
  - How to get to a supply chain – engineering; but first select exactly what IT is!
  - Why do it? Number of skill sets encountered/needed? Sales considerations!
  - What to do first? Design for market? For manufacture? Technology first?
  - Timing – all in due time? Chicken and egg? When? Financial considerations!
  - Analysis or luck? Myth/misunderstanding of the “aha” moment?
  - RISK – balance market/sales, technical, financial, personal.
  - Silicon Valley – is it an accident?
    - never apologize for failure; reward success; people agnostic.
- Invention vs Innovation; the complex device and integration into application.
- Large company vs Small company – culture clash
  - Approach to market; you must become quality managers and more
  - Production – need ME to make hardware even if you are a chemist or EE!
  - Loss of sales just because you are new, small, or unknown.

Why worry about sensors?

- VISION: HEALTHCARE FOR ALL; CLEAN AIR AND WATER with CLEAN SUSTAINABLE FOOD for all; CLEAN ENERGY FOR everyone everywhere!

Can you imagine doing all this without sensors?

Sensors are a major part of analytics!

GRAND CHALLENGES – NAE

ADVANCE HEALTH INFORMATICS
ENGINEER BETTER MEDICINES
ACCESS TO CLEAN WATER
RESTORE/IMPROVE URBAN INFRASTRUCTURE
MANAGE THE NITROGEN CYCLE
REVERSE ENGINEER THE BRAIN
ADVANCE PERSONALIZED LEARNING
PREVENT NUCLEAR TERROR
ENHANCE VIRTUAL REALITY
SECURE CYBERSPACE
DEVELOP CARBON SEQUESTRATION
MAKE SOLAR ECONOMICAL
PROVIDE ENERGY FROM FUSION
ENGINEER THE TOOLS OF SCIENTIFIC DISCOVERY

WHY WORRY ABOUT GAS SENSORS?

HUMAN HEALTH

PLANETARY HEALTH

TECHNOLOGY

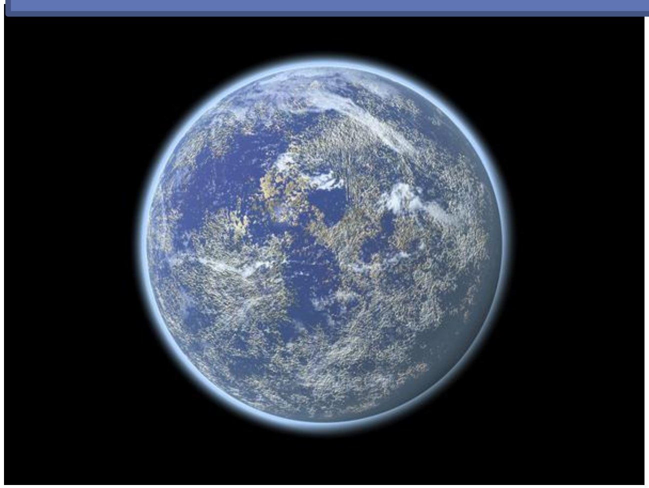
FINANCIAL GROWTH – ECONOMICS!

AIR POLLUTION - AIR QULAITY - GLOBAL

The 4th leading cause of the human disease burden.

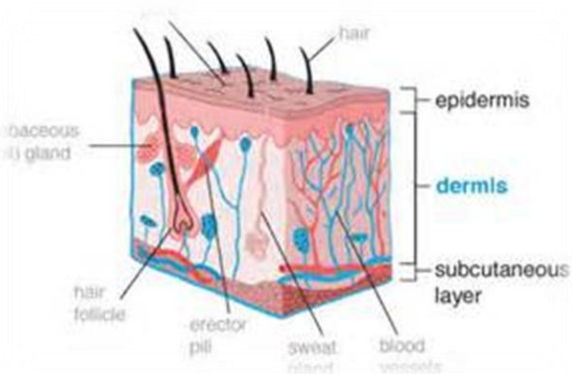
Major cause of global warming disasters.

Major threat is mendacity, resource distribution, and ignorance.

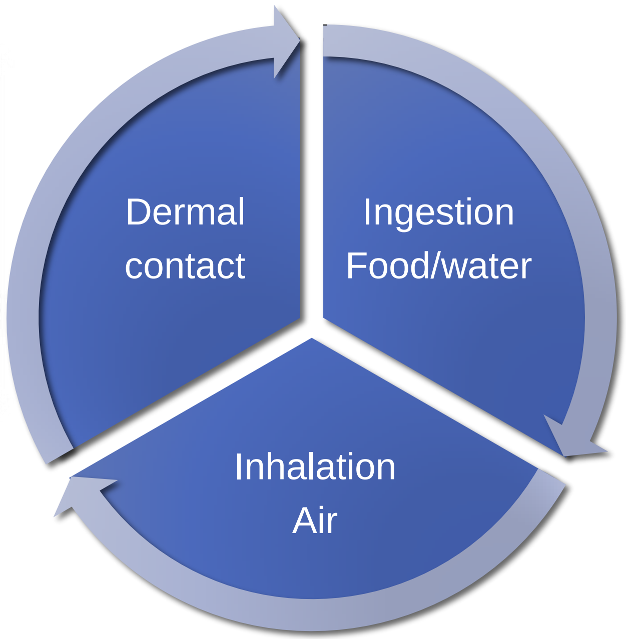


Relative Volumes of Earth and our air [right] and our water [left]

How Are Humans Exposed to Insults?



Skin Penetration



Contaminated Food

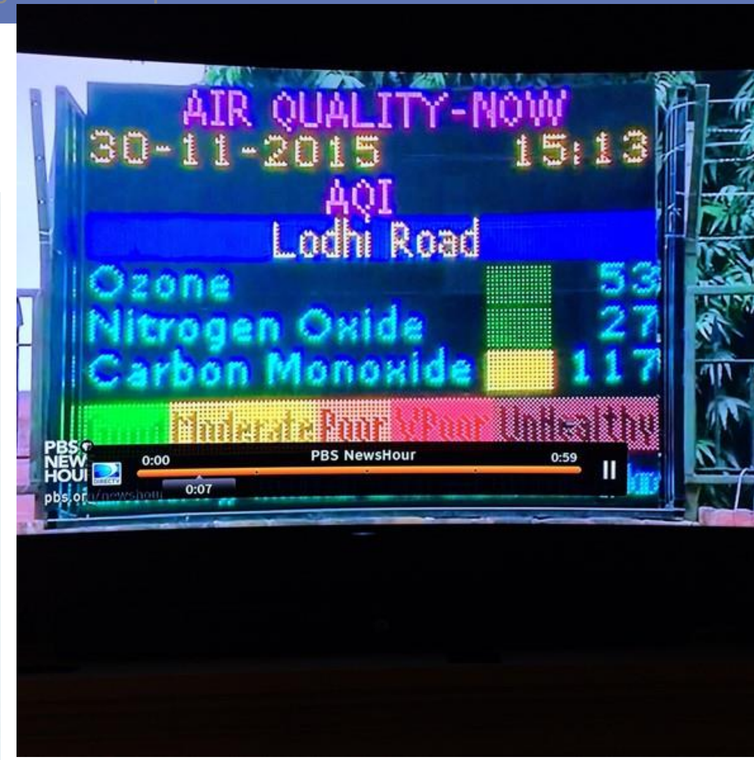
The EXPOSOME!

Our exposure is the key to our well-being! Wild, Christopher P. *Cancer Epidemiol Biomarkers Prev*, 2005; 14(8): 1847-50.

Inhaling of Gases & Vapors

Gas Sensor focus

WHEN?
Think now!



Death by Breath – Study Reports that about 50% of Delhi school children have irreversible lung damage! Delhi is 50th in rank as world's most polluted city – Beijing 79th!

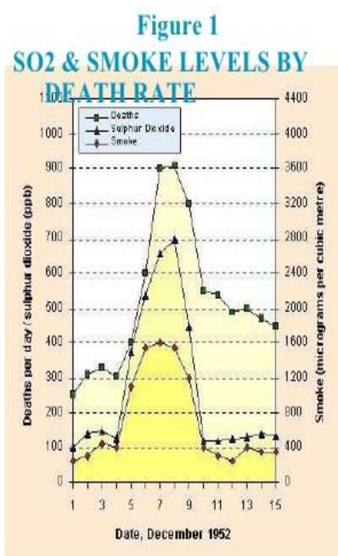
Written by **Aniruddha Ghosal** , **Pritha Chatterjee** | New Delhi | Updated: April 2, 2015
http://indianexpress.com/article/india/india-others/
landmark-study-lies-buried-how-delhis-poisonous-air-is-damaging-its-children-for-life 5:20 pm

Our People, Our Air; the story of Mankind and Our Environment! [examples of the misuse of science;

Pb, cigarettes, love canal and chromium VI ---- now climate change.]

HISTORY

- December 4th 1952, → fog;
- Smog lasted for 5 days & led to 4000 more deaths than usual.
- The deaths were attributed to the increase in air pollution during the period, with 7 fold ↑ in SO_2, and 3-fold ↑ in smoke than before
- The peak in the number of deaths coincided with the peak in both smoke and SO_2 pollution levels.



Numerous epidemiological studies associate air pollution, even chronic low level pollution (CO, NO2, O3, SO2, particulates) with:

- ❑ **mortality [any of them]**
- ❑**Premature death**
- ❑ **emergency room visits, hospital admissions**
- ❑ **respiratory irritation and lung disease**
- ❑ **low birth weight or defects or premature birth**
- ❑ **neurological damage**
- ❑ **cardiovascular disease**
- ❑ **hematological disease**
- ❑ **cancer**

N. Notman, “City Air,” Chemistry World, V14 (2), 2017 pp16-19.
“Urban pollution is clearly a growing problem;
Particulates are important; but NOx, SOx. Ozone and CO are key.”
EPA Criteria Air pollutants: CO, NOx, O3, SOx, Particles, Pb [+187VOCs].

Globally, 3.7 million deaths were attributable to outdoor air pollution in 2012 and air pollution is linked to 1 in 10 deaths of children under 5 years old. **- Source: World Health Organization**

“Almost everyone on Earth now breathes polluted air!”

92% of the world's population lives in places where outdoor air quality fails to meet WHO guidelines.

Actionable information at the neighborhood and street level comes with global net!

CNN http://www.cnn.com/2016/09/27/health/air-pollution-map-who/
World Health Organization

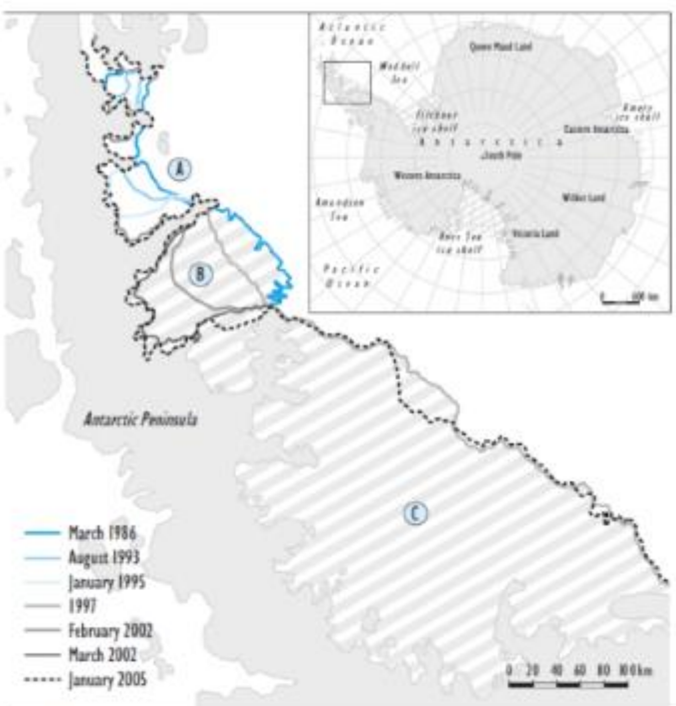


Figure 4.5 Decline of the ice shelves of the Antarctic Peninsula since 1986
The lines show the ice boundaries in different years.

The Larson C ice shelf; 20,000 sq mi, now has a 11 mile and ever wider crack; can cause seas to rise.

The last remaining section of Antarctica's Larsen B Ice Shelf — 625 square miles, a barrier to keep glaciers from melting into the ocean, is rapidly disintegrating and expected to disappear by 2020 [NASA report May 2015]. Global sea levels rise.

? WHAT IF ? Polar ice melts and seas rise and 1/2 the state of Florida is under water and
New York has to be moved inland, extreme weather persists, droughts worsen, food prices rise, forest fires rage, coral reefs disappear, species vanish, pollen allergies increase, invasive species cause massive deforestation, animal migration changes, and snowcapped mountain peaks are history!!!

KWJ ENGINEERING INC INNOVATIVE SOLUTIONS FOR GAS DETECTION

SPECSENSORS

Sensors: in line with biggest the ECONOMIC tides!

TSensors Summit
Trillion Sensor Roadmap

October 23-25, 2014
Stanford University; Palo Alto, CA
J. Bryzek; www.TSensors.org

- Mobile markets
- Wearable markets
- Internet of Things and Everything
- Mobile Health
- Exponential Technologies
- Exponential Organizations

GLOBAL GDP REVOLUTIONS

- In the 18th century, GDP depended on the size of population.
  - China and India dominated global DGP.
- 1st GDP Revolution: steam, electricity, internal combustion, radio, aeronautics.
  - Europe started to dominate global GDP.
- 2nd GDP Revolution: transistor, computer, internet.
  - US and Japan started to dominate global GDP.
- Emerging 3rd GDP Revolution fuses ***computing***, ***communication*** and ***sensing***.
  - Expected to free people from manual labor, leaving for them creative work.

Zero/Small impacts without economic driver!!!!!

KW ENGINEERING INC

SPECSENSORS

What is a sensor?

- World of sensors?
- Gas sensors?

What is a sensor? My Quest!

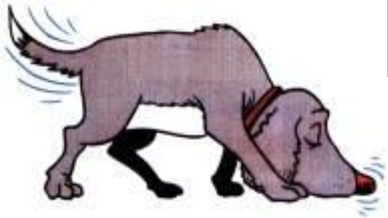
the "perfect" chemical sensor!

- Measures everything
- Unambiguously
- Immediately
- No maintenance
- Tiny, lightweight
- And, of course!
- **LOW COST!**

tricorder

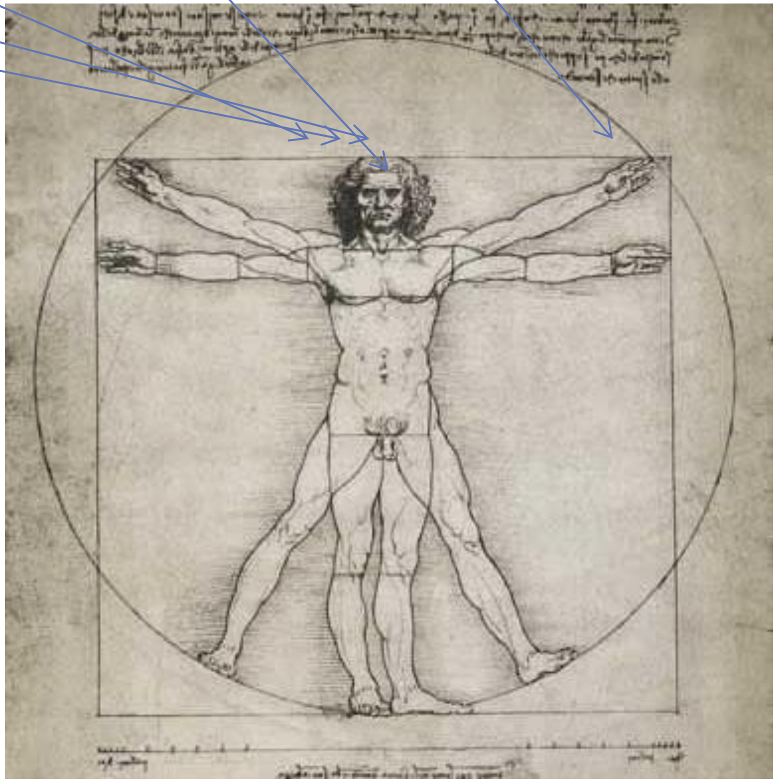
KWJ ENGINEERING INC INNOVATIVE SOLUTIONS FOR GAS DETECTION

SPECSENSORS



what IS A SENSOR?

YOUR EYES, NOSE, EAR, TONGUE, TOUCH



- Sensors Provides Input
- Sensors MAKE YOU
  - AWARE
  - Safe, protected
  - conscious
- Sensors ENABLE action
  - Navigation, food intake
  - Decisions – fight, flight
  - Work and play
    - Recreation and procreation

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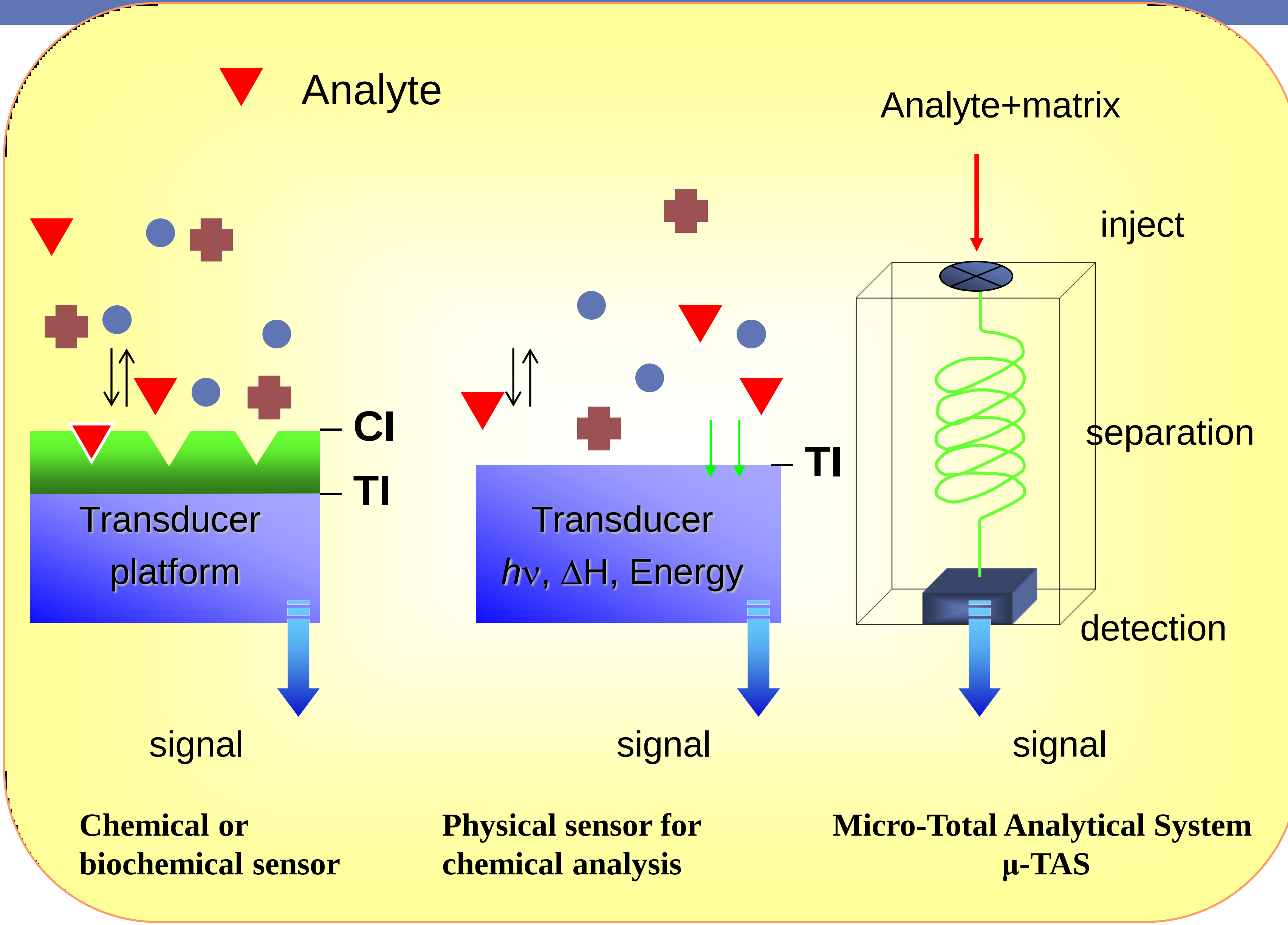
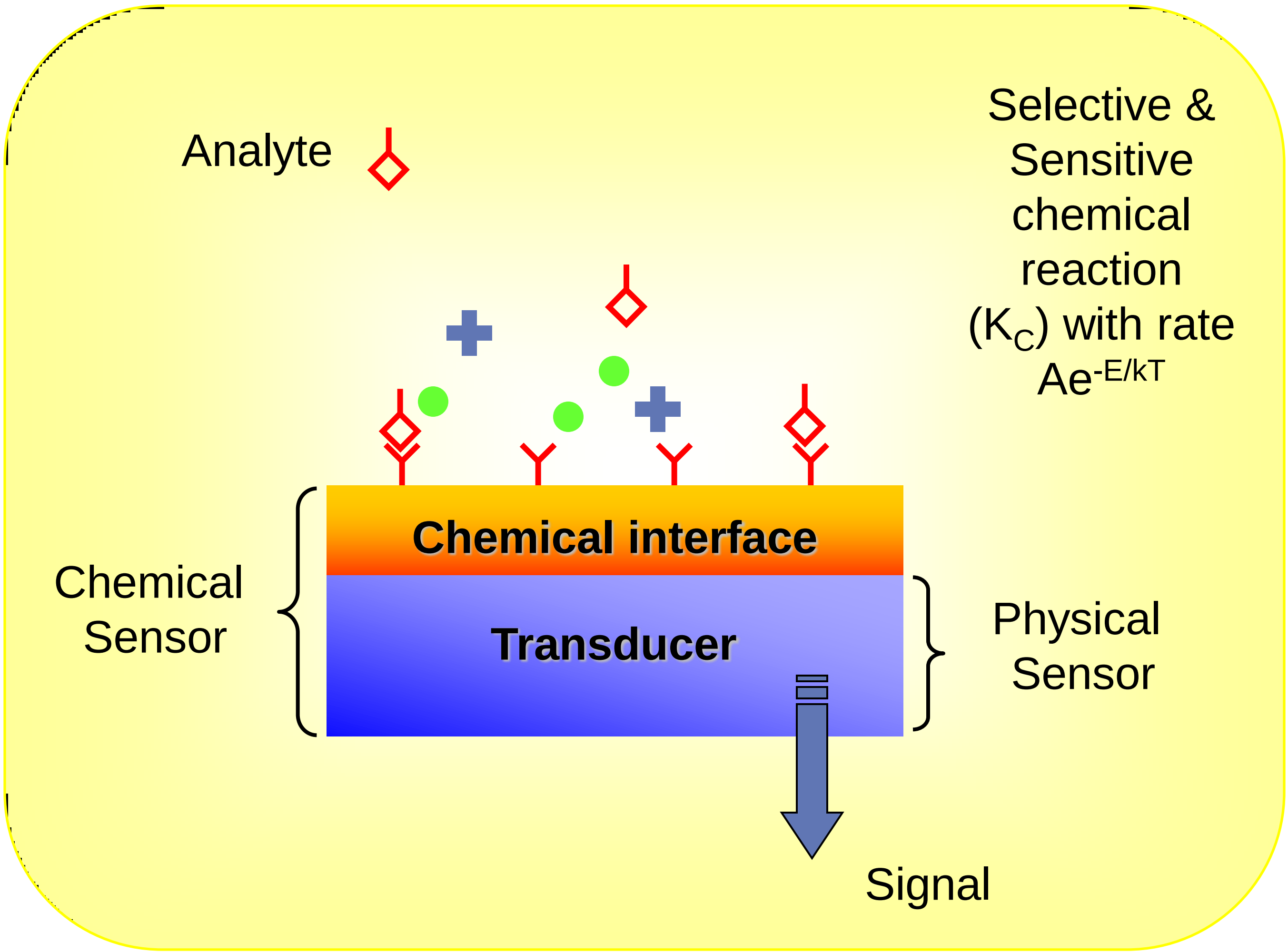
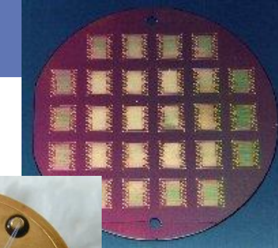
SENSORS

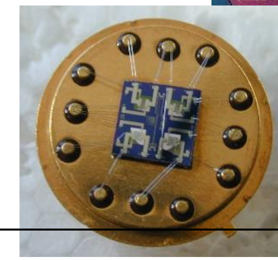


Three types of sensor design and operating principle. All can be used in arrays!
CI: chemical interface, TI: transducer interface.

THE CHEMICAL SENSOR







ORGANIZATION OF THE FIELD

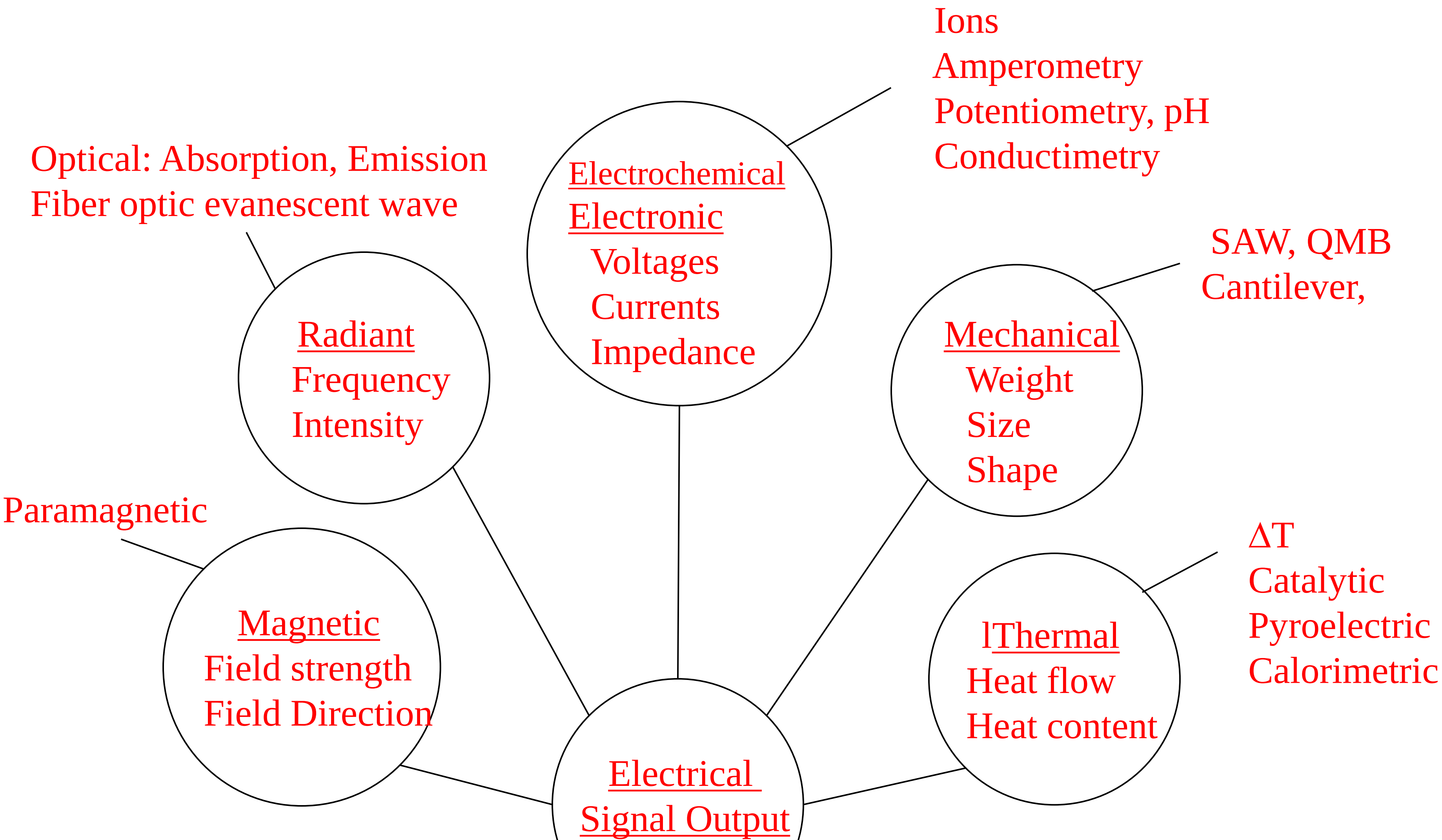
-Sensor CLASSES→ TYPES; PLATFORMS; technologies;

-THE 5 SENSOR CLASSES

ELECTRONIC	ELECTROCHEMICAL	OPTICAL/mag	MECHANICAL	THERMAL
-CHEMIRESISTOR -HMOx -Cond-Polymer -Nanotube -CAPACITOR -INDUCTOR -IMPEDANCE, Z	-Potentiometric ISFET Zr O2 -Amperometric -Toxic gas Conductimetric	-ABSORPTION IR, UV, vis -EMISSION fluorescence	-Piezo- electric -Resonant w/sorption	-TCD -Catalytic -ThermoEL -Pyro- electric

PLATFORM - DEVICE and COMBINATIONS of material/structure/method; different response mechanisms.

FET	**ISFET**	**EVANESCENT WAVE**	**SAW, BAW**	**HOTPLATE/EL**
Bottom gated FET		**OPTICAL FIBER**	**CANTILEVER**	**THERMO-EL**
Diode	**SPECTRO-ECHEM**			**PELLISTER**



Chemical Sensor Diversity

Transition of sensor technology to market: innovation vs invention

- Focus on the fundamentals; define sensor properties in a uniform way – like the market spec sheets do – they compete on well known parameters
- Understand what is value proposition and work on that
- Cost is very important but must be uniquely understood.
- 3 – Differentiators
  - Cost; performance; service.
- Invention = better mousetrap
- Innovation = do something different
  - with social impact

Disruptive Requirements:

- **Extremely small**
- **High Performance**
- **Ultra low power – u-watts**
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The 3 Characteristics that define a **reliable** measurement: ***precision, accuracy, validity: all sensors!***

1.] Signal, S_a=(S -S_0), [S/S_0 – 1] at [a]; and noise, N*

2.] SENSITIVITY, μ = slope of S_a vs [a] curve at a_i: dS/da

3.] SELECTIVITY – relative sensitivities; μ_a/μ_b

4.] SPEED OF RESPONSE – $t_{90\%}$, $t_{95\%}$, …

5.] STABILITY of above 1, 2, 3, 4

with time, conc./matrix, T, P, RH, …. over

- short time - noise; or
- long time - drift

- $$$$, Size/shape, weight, application specifics, ……..

*N = noise in signal units; used to express S/N ratio, LDL or LOD, and analytical sensitivity [noise/slope; $uA_n/(uA_s/ppm)$].

PRECISION, ACCURACY, VALIDITY MUST COME FROM SENSOR SIGNALS! There is a need for more standardization!

DRAKE EQUATION INSIGHTS!

Publications = S/[C] + Si + S + S/n + $$$ = success

Commercial = S^5 for success (within a market requirement)

- SENSORS SPECIFICATIONS – S^5
  - SENSITIVITY – S/[C], relates to LDL, alarm levels, monitoring
  - SELECTIVITY – defines n-dimensional response of sensor
    - Concentration, time, temp, pressure, temperature, vibration, stress, …
    - Compensate by design, hardware, or software
  - SPEED OF RESPONSE – rise, decay, transient.
  - STABILITY – noise [short term], drift [long term]; zero, span, performance
    - Measured parameter over drift dimension
  - $$$ - logistics – cost, size, weight, power, circuits, lifetime, …

- ***POISONS; extended monitoring and exposure, corrosion, salt, power washers, compressed air, fault monitoring, self-supervision, battery power, small size, …. UL, EN, and other certifications.

KWJ ENGINEERING INC INNOVATIVE SOLUTIONS FOR GAS DETECTION

SPECSENSORS

CASE STUDIES

- Paths to market
- Sensors to Market links
  - Sensors + analog + digital + signals + AI + power + comm
      - Smart cities - environmental
      - Wearables – COEL by Intel-Grameen [Flex]
      - Fixed site health – Asthma lung irritant monitor
      - Breath analysis
      - Cell phone cases
      - Sensor fusion
      - Technology roadmap

MOTIVATION and APPLICATIONS

MARKETS, SALES, PRODUCTS

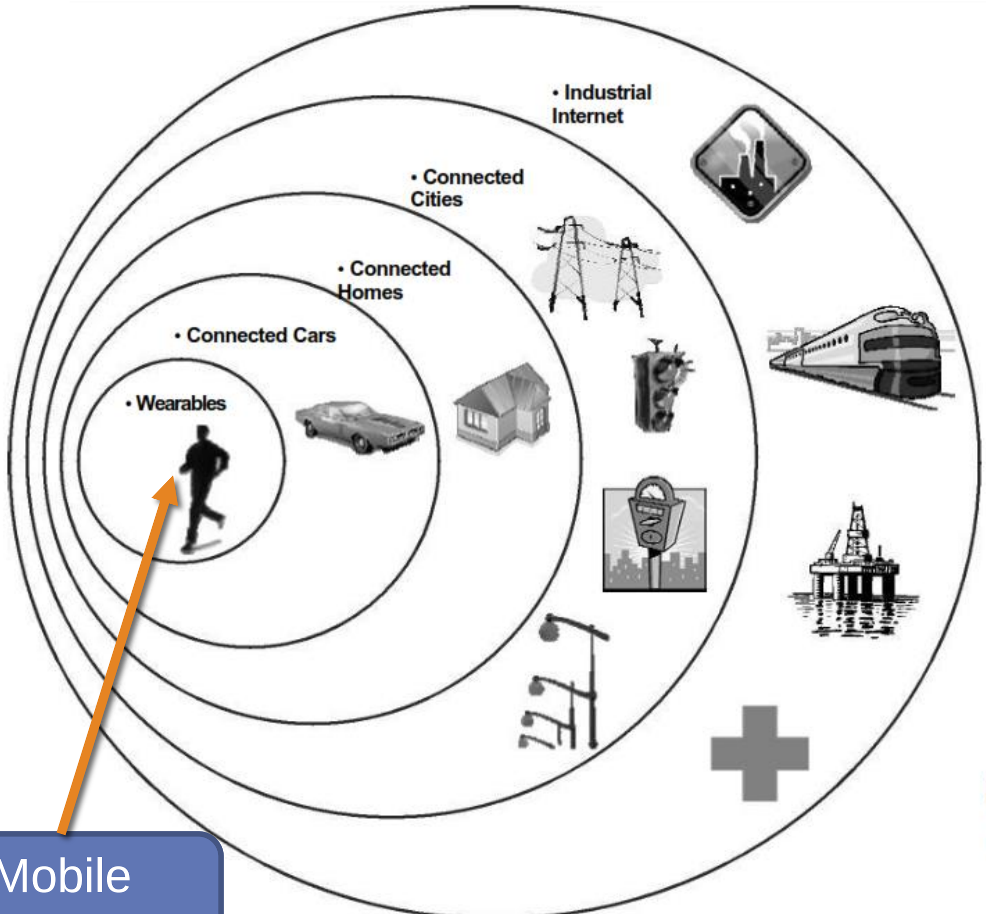
KEY CHALLENGES

- Materials – properties, costs, applicability, qualification
- Geometry – response control, packaging.
- Methods – specifications; range, T, P, RH; algorithms,
- Logistics – size, manufacture, cost, certifications,

- Orchestra leader required!

Where We Play – sensors are crosscutting; markets success is vertical

IoT can be broken up into five key verticals of adoption: **Connected Wearable Devices, Connected Cars, Connected Homes, Connected Cities**, and the **Industrial Internet.**



Mobile platforms

- **The IoT can only be enabled by breakthroughs in the cost of ubiquitous sensors for collecting and sharing data**
- **Products like Fitbit and wireless thermostats are already gaining traction.**

Really?

Fitbit measures steps taken, Calories burned, Activity vs. inactivity, Sleep quality, Distance traveled.

Fitbit debut with a $6.5B IPO June 18, 2015

•Source: Goldman Sachs Global Investment Research.

The Goldman Sachs Group, Inc. Global Investment Research (2014)

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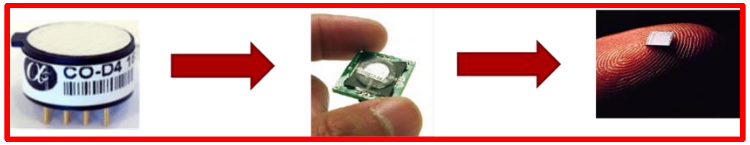
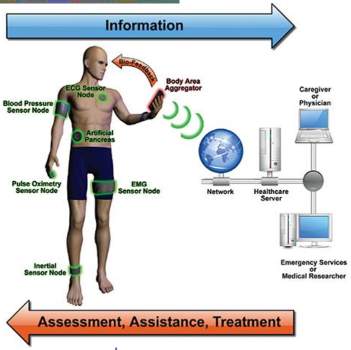
Gas Sensors Evolve for Societal Well-Being: Trends and Movements

- ❑ **Occupational Health and Safety**
- ❑ **Environmental Sensors**
  - ❑ Air Quality
  - ❑ Indoor air
  - ❑ Exposome
- ❑ **IoT**
  - ❑ Smart Cities
  - ❑ Smart Cars
  - ❑ Smart homes
- ❑ Wearables
  - ❑ health/fitness/sport
  - ❑ e-Health monitoring
  - ❑ e-health diagnosis
  - ❑ Independent living





Smaller/Lighter/ Lower Power/Connected

Wireless/wired connectivity
Mobile (e.g., in/on phone)
Smartphone/tablet apps

Sensing+
Computing+
Communicating =
GDP Revolution;
$20B?

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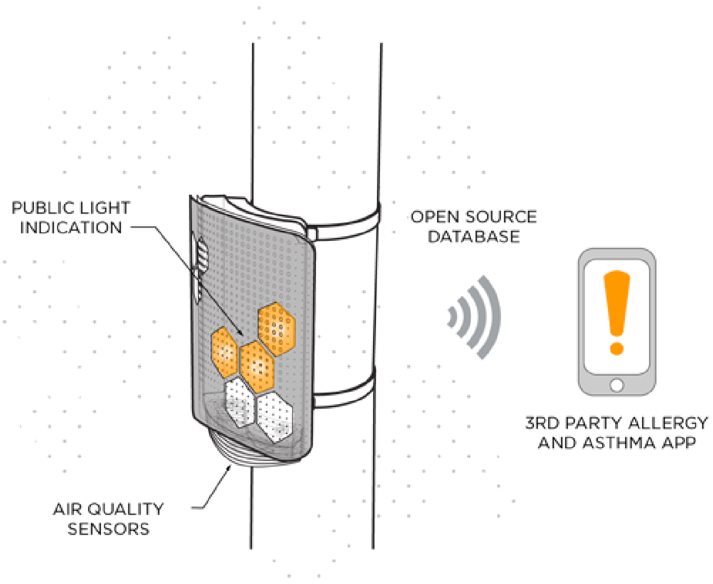
Array of things - Chicago

“fitness tracker for the city – 500 nodes by 2018, all open source information!

Factors affecting quality of life

Actionable information

- ❑ environmental sensors
  - ❑ temperature
  - ❑ humidity
  - ❑ atm pressure
  - ❑ sound intensity
- ❑ Air Quality Sensors
  - ❑ NO2
  - ❑ O3
  - ❑ CO
  - ❑ H2S
  - ❑ SO2
- ❑ Light & Infrared Sensors
  - ❑ surface temperature
  - ❑ pedestrian and vehicle traffic

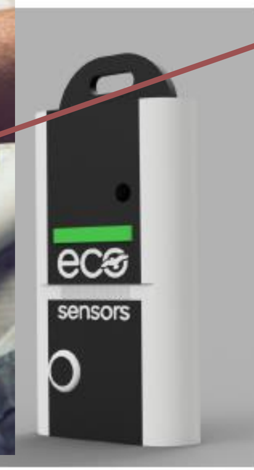


https://arrayofthings.github.io/

- o Urban Dwellers
- o First Responders
- o Building inspectors
- o Small Airplane Pilots
- o Commercial Aircraft
- o Power Boat Owners
- o Houseboat Owners
- o Remote Car Starter Owners
- o Car Owners
- o Self-Insured Companies (especially with field workers)
- o Travelling Executives
- o Pregnant Women
- o Parents of Small Children (schools/daycare)
- o People with Respiratory/Heart Problems
- o Elderly, asthmatics
- o Exercise, sport, …
- o Gas Appliance repair people
- o Firefighters
- o Campers/outdoorsmen
- o RV Home owners

TECHNOLOGY FOR IoT – Eco-Sensors

- New technology combines - sensing computing and communication!
- Sparrows live across the globe and their disappearance is a symbol for ecological imbalance! Sparrow CO–2017!



Otterbox "rail"!

low cost monitor

0-1000 ppm CO

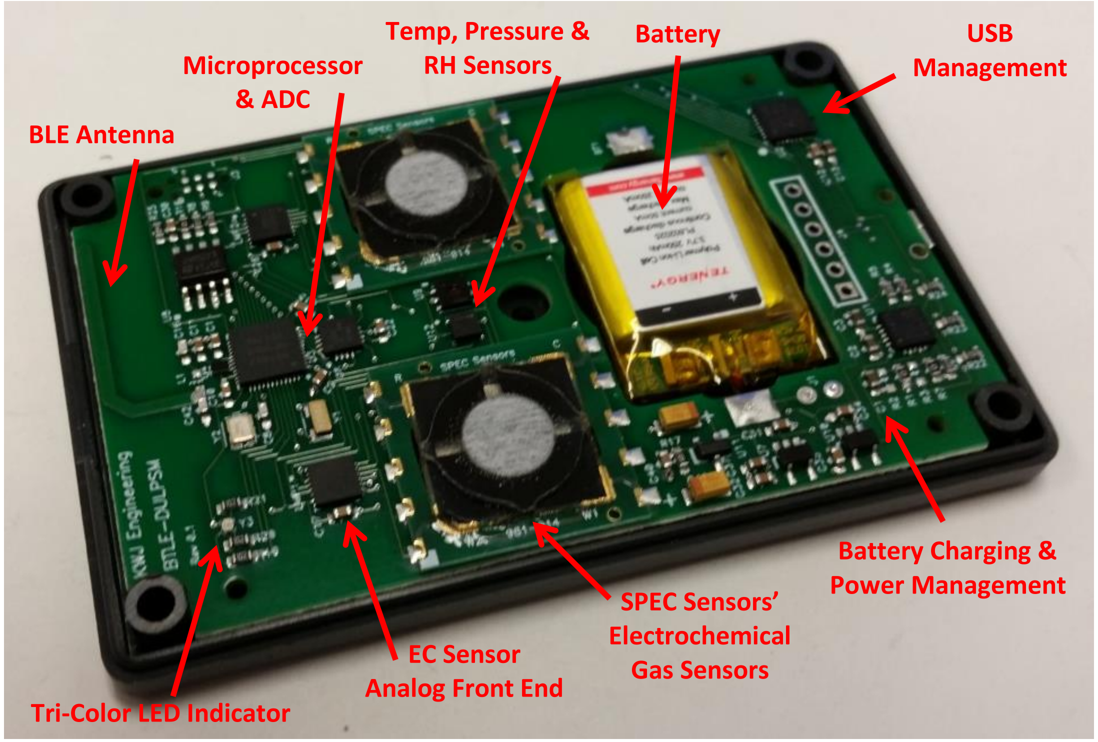
alarm for health

alarms for safety

SPARROW

https://www.indiegogo.com/projects/sparrow-wearable-air-monitor-by-eco-sensors#/

Dual Digital Gas Sensor Module



- ❑ microprocessor controlled
- ❑ 24 bit A/D conversion
- ❑ on-board temperature and relative humidity compensation
- ❑ Bluetooth LE/USB communications
- ❑ Battery life 62 h and 1 y depending on measurement/ broadcast duty cycle.
- ❑ Wireless data is transmitted to phone/tablet

3.3 x 2.1 x 0.4 in. enclosure

Applications:

- ❑ Home monitor
- ❑ Personal monitor – wearables
- ❑ Point sensors for environmental monitoring

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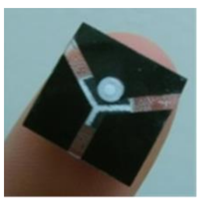
Technology Roadmap - Sensors

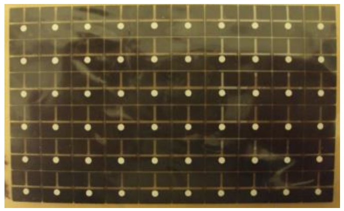
TAM
$1 Billion

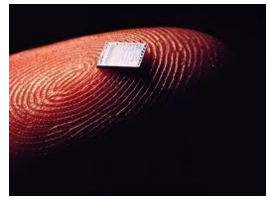
Industrial
Wireless
Residential



Phase I Printed CO Sensors
Phase II MEMS

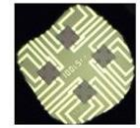
$10 Billion

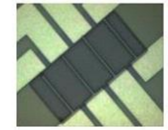




Smartphone Consumer Use
Integrated, ubiquitous part

$100 Billion





Conformal Devices
Diagnostics/Breath
Lab on Chip

Phase IV
Seamless Integration

Phase III and Beyond:
Size Reductions – Sensor Arrays

Phase II Printed Sensors/MEMS – Standardization, Device Integration

Phase I Printed/MEMS Sensors – Size and Cost Advantage

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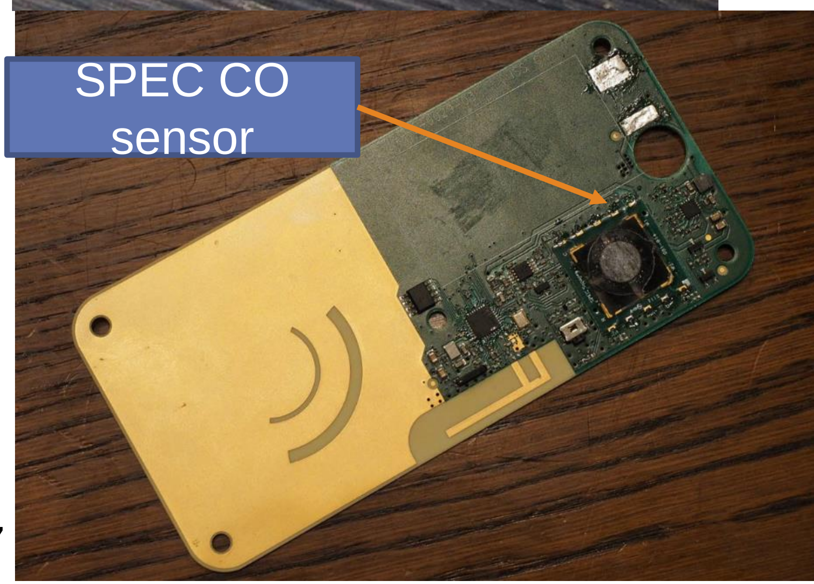
SPECSENSORS

Business Model: "Cleanspace" app monitors CO; offers rewards for clean miles; sell data with actionable information.

drayson™
WIRELESS



Planned 100K IoT deployment, London 2016-17

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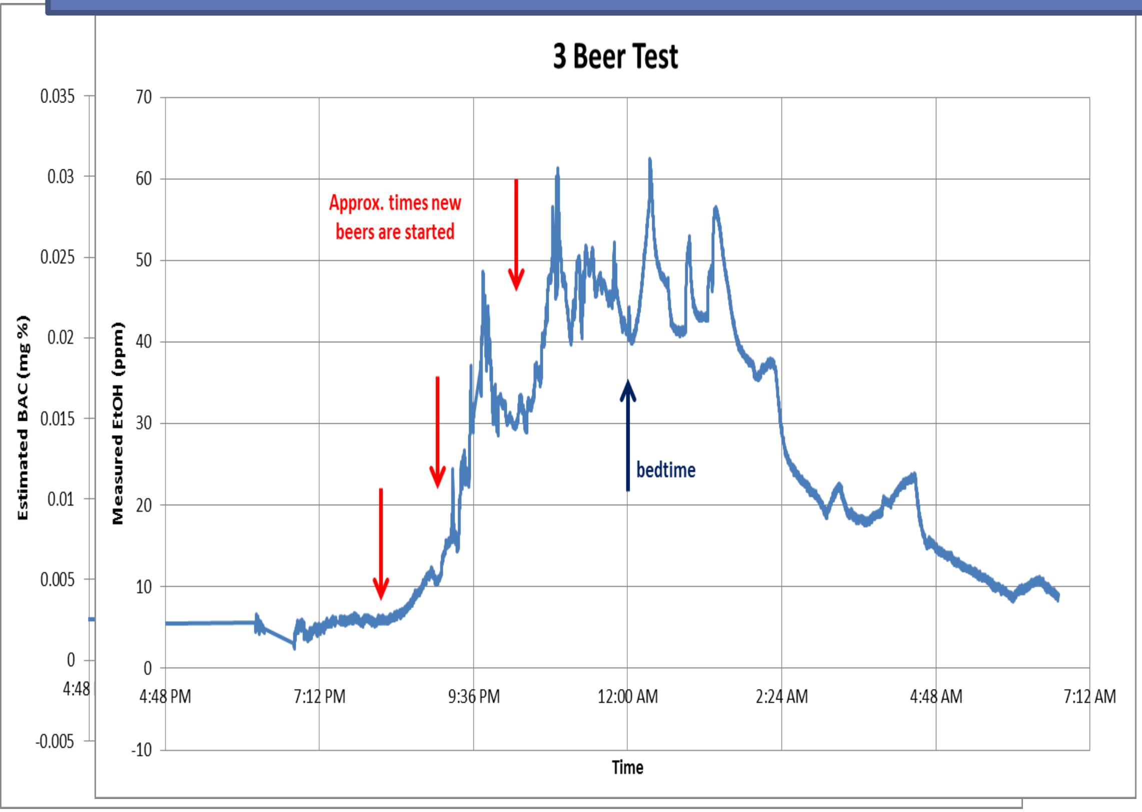
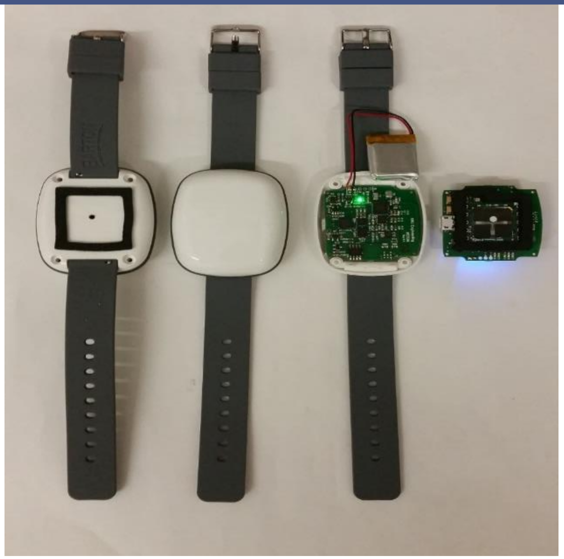
SPECSENSORS

One more example! Smart drinking demo!

KWJ watch “demo” with SPEC Ethanol sensor: transdermal alcohol has a 30 minute delay but could be fun to use and lead to more responsible drinking!





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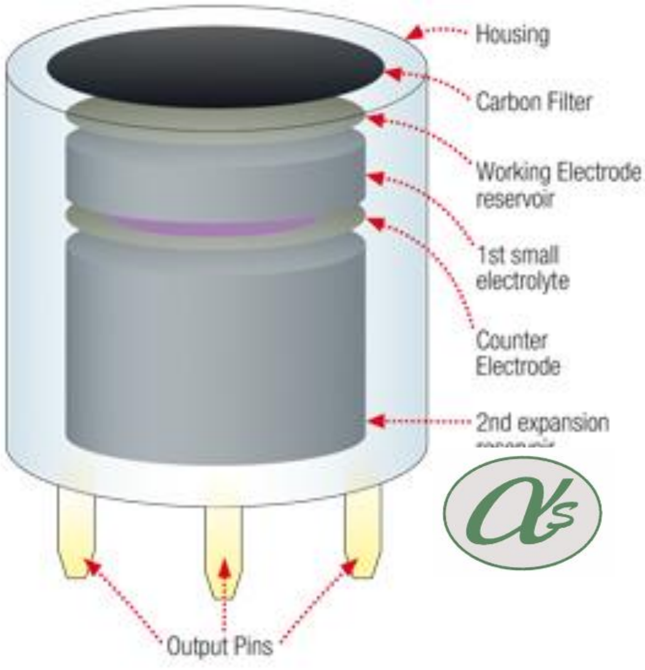
SPECSENSORS

- Summary – MDRD + constant review is required
  - VISION TO THE FUTURE LEADS THE WAY
    - Idea to Product is hard work and has evolutionary learning component.
  - There must always be market drivers
    - existing, new – large volume can have large impact.
    - Value proposition: info/cost
    - Must buy vs like to buy
    - In a strong wind, even turkeys fly.
  - Budgets and timeline risk evaluation is essential
    - Timing is everything; cardinal rule is “do not run out of cash” ever!
    - Markets develop on their own time; products are similar.
    - Focus, but cover a wide space?

Technology Journey:
how to validate a 10yr lifetime in 1 year!

Why Amperometric Gas Sensors?



Patented Surecell™ Two Reservoir Design

manufacturing paradigm shift

Materials
Design
Process

SPEC SENSOR
New design-new proess
Size= 15x15 or 10x10 mm,
1-3mm thick, Zero power,
10-year lifetime; CO, NO2,
O3, SO2, H2S at ppb levels.

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Amperometric Electrochemical sensor evolution 1980-now!

performance

Size/power

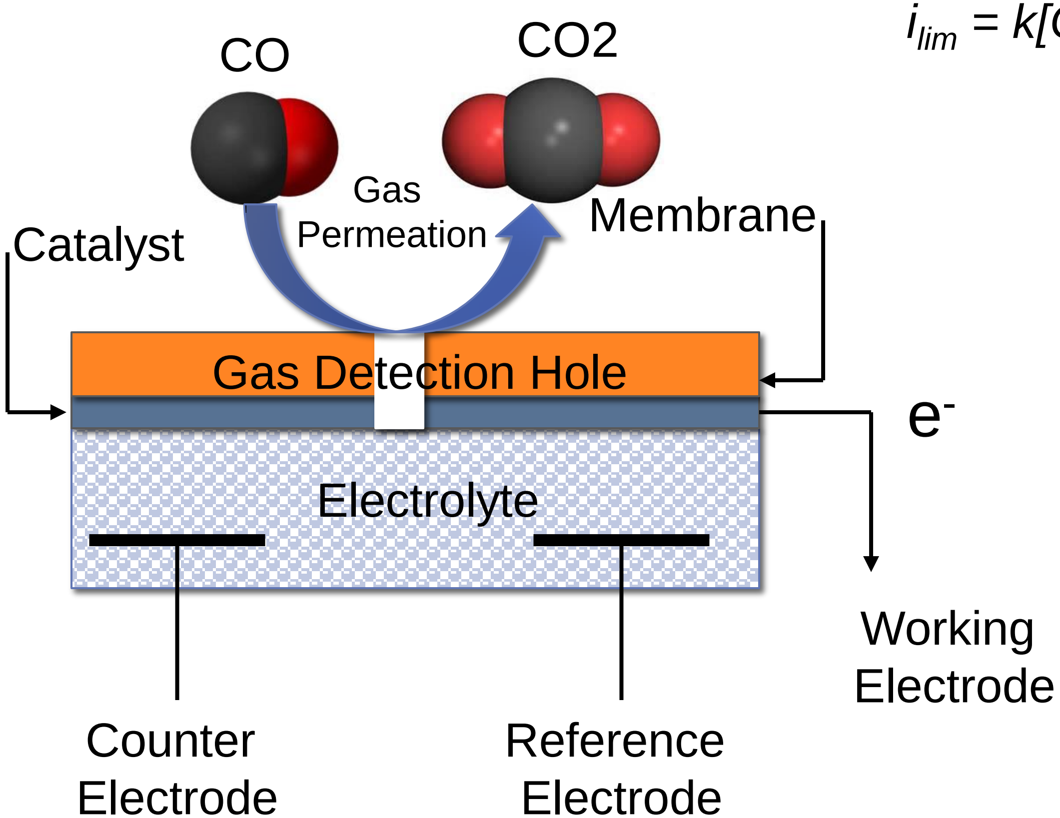
The Past **Today** **The Future (SMT)**

Existing market changes
= specification changes

SPEC Sensor Working Principal

$CO + H_2O \; = \; CO_2 + 2H^+ + 2e^-$

$i_{lim} = k[CO]_{gas}$



$1/2O_2 + 2H^+ + 2e^- \; = \; H_2O$

Self-Contained /sealed

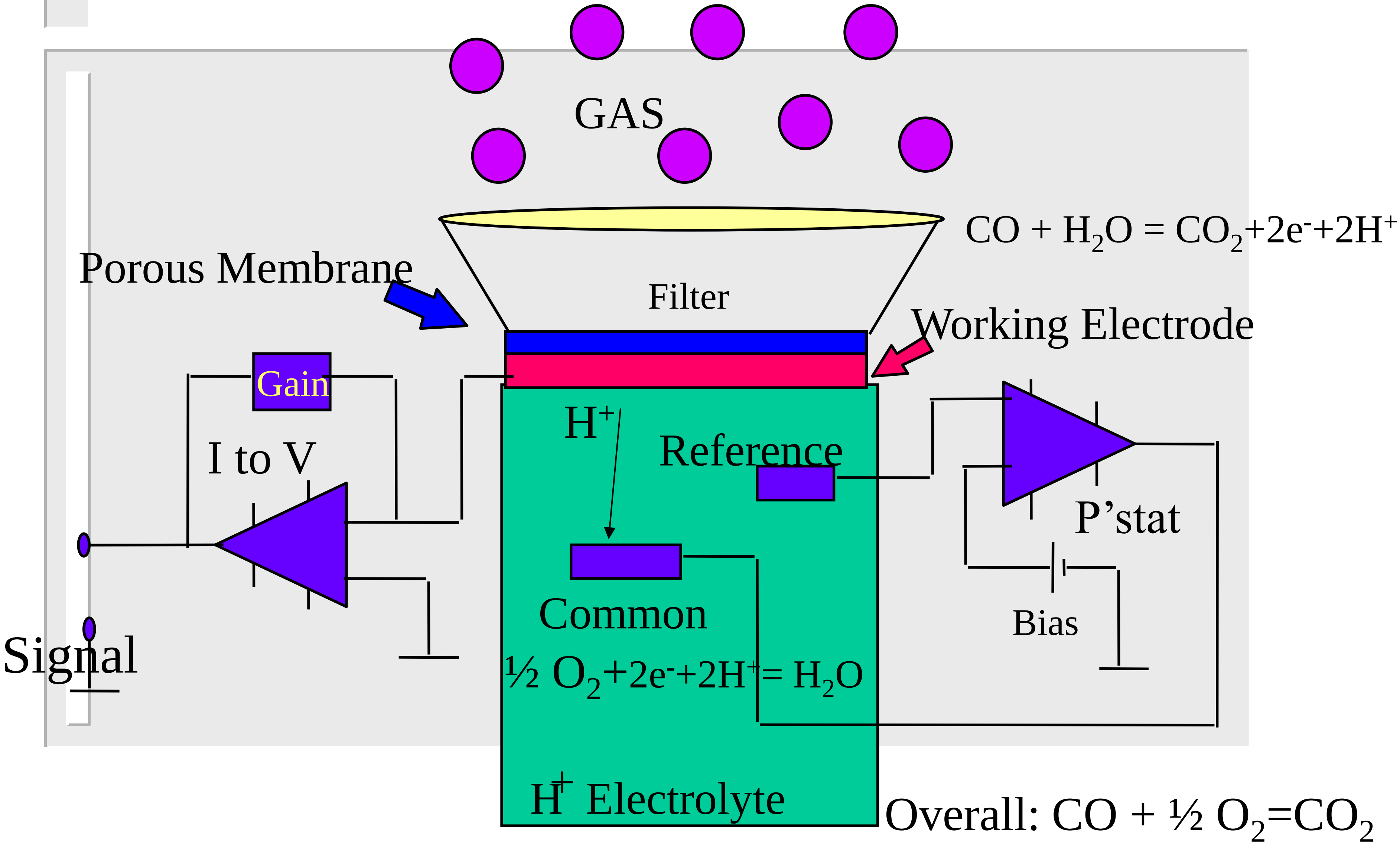
Zero Power

Catalytic

$1/2O_2 + CO = \; CO_2$

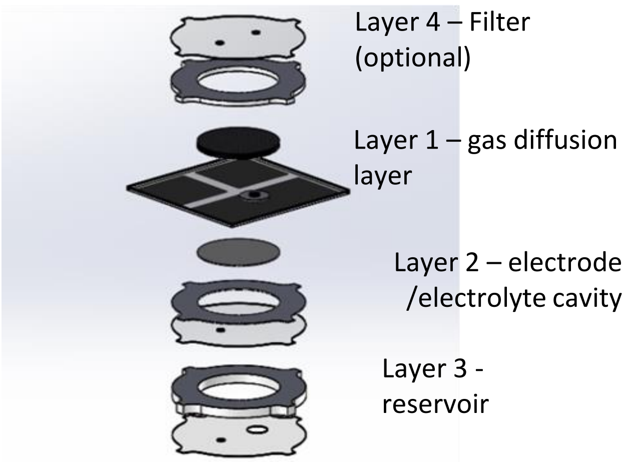
Reaction occurs in a tiny cell fast, reversibly, indefinitely, selectively, at low power

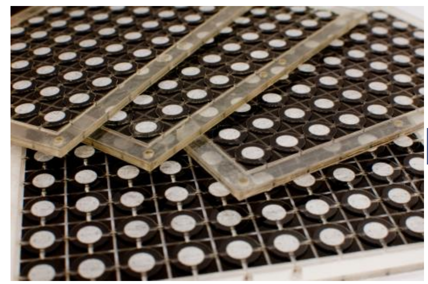
Amperometric Gas Sensors, e.g. CO

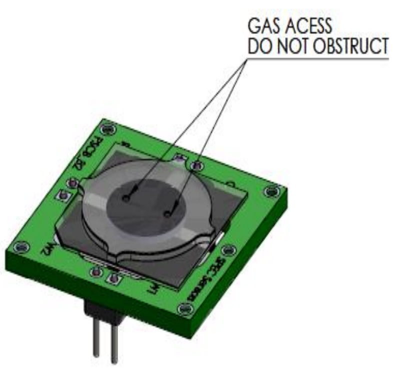


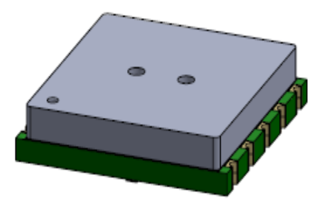
Printed Sensors: bridge cost-performance gap

Layers add and subtract; scalable wafer paradigm; dice and mount, use semi-fab model! Future=Flex-printed R2R!









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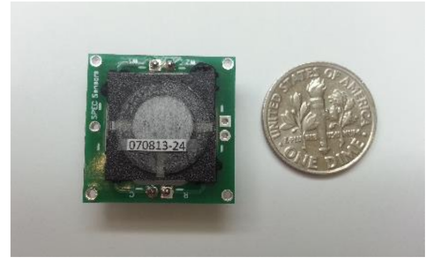
Printed Sensors – why AGS? Why print?



WHY AGS?
Toxics – CO, O2, O3, H2S, ROH, NOx, SOx, Cl2, NH3, and more.
Proven: >40 yrs of Industrial success
"Performance is Evidential"

- **Small and Thin**
- **Low materials use/electrolyte volume**
- **Scalable printing, lamination, 60/sheet**
- **Low power (microwatt)**
- **Low production cost (printing)**
- **Compatible with industry standard designs (e.g., SMT, laser dice, flex, pcb mount)**
- **Performance specs equal to or exceeding high end conventional sensors; CO sensor meets UL2034 certification.**

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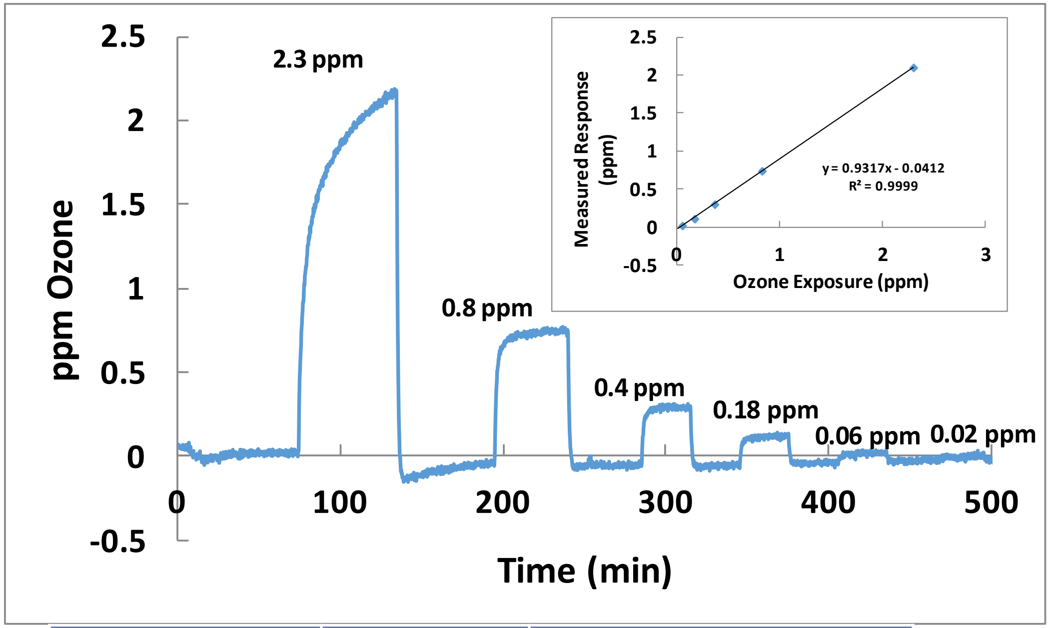
Ozone gas sensor with CNT working electrode: first trial!



Specification	SPEC 3SP-O3-20 Printed Sensor	Alphasense OX-A421 Benchmark Sensor
Sensitivity (nA/ppm)	20-40	200-425
Response time (s)	<20	<60
3σ noise (ppb)	20-30	23
Cross-sensitivity	H_2S, NO_2 , Cl_2	H_2S, NO_2, Cl_2

- wired O_3 monitor 10 s/point
- 0 – 2.3 ppm O_3 in air at 25 ^oC.
- aqueous acid electrolyte.
- sensor output was very stable and linear over this long test (ca. 8.2 h)
- limit of detection (LOD, based on 3σ of baseline noise) was 28 ppb O_3. This is within one order of magnitude of our target resolution (5 ppb) for the practical device.
- Cross reactivity -1:1 NO_2

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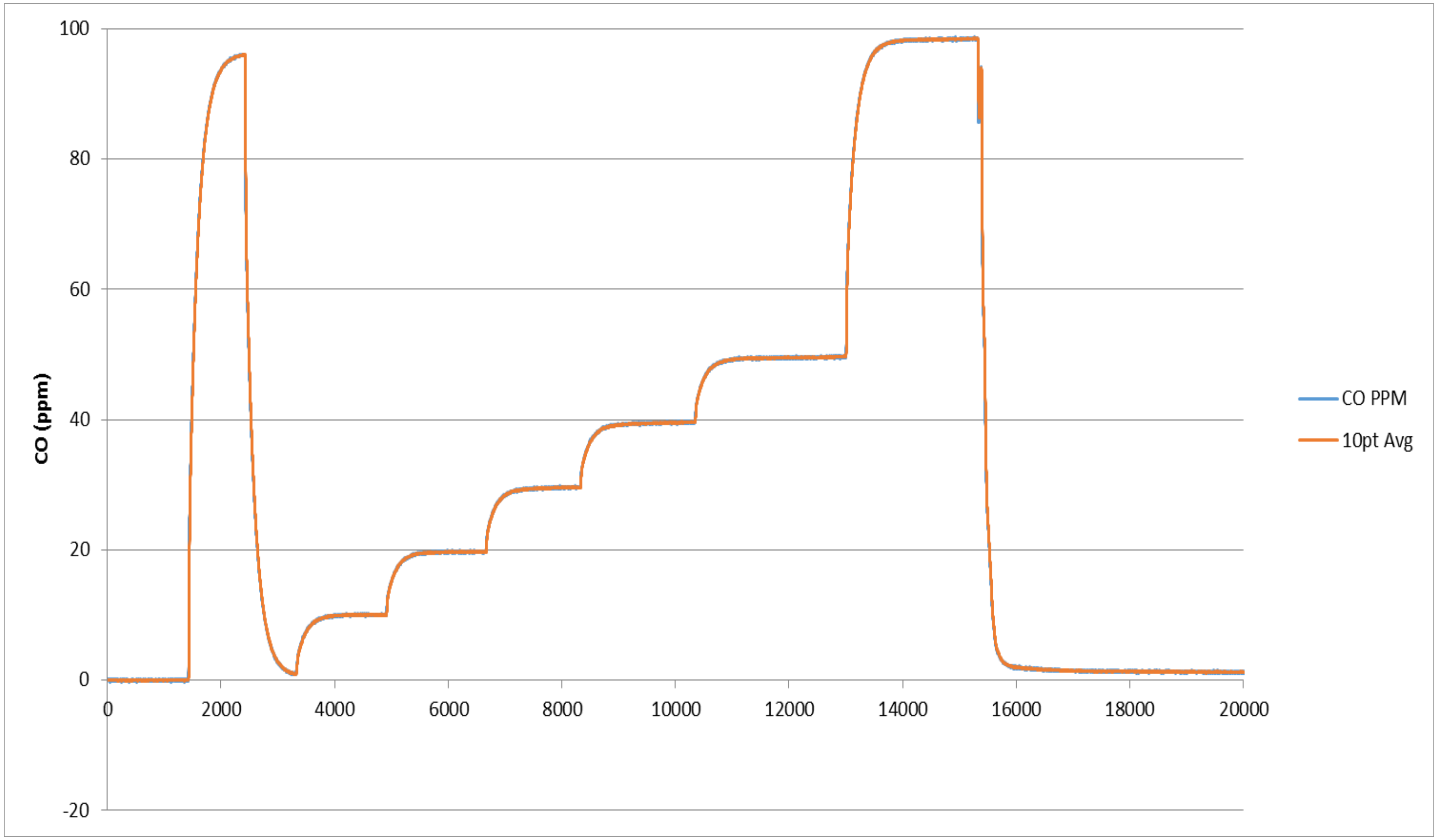
Carbon Monoxide – submicron catalyst cake electrode.



BTLE-ULP #	Sensor #	S Code (nA/ppm)	Measured S (nA/ppm)	% Diff	3σ LDL (ppb)			R^2 Linearity
					RAW	10pt AVG	50pt AVG	
1	051115011614	5.19	4.88	-6.0%	250	90	16	0.999983
2	051115012049	6.32	5.65	-10.5%	196	93	22	0.999988

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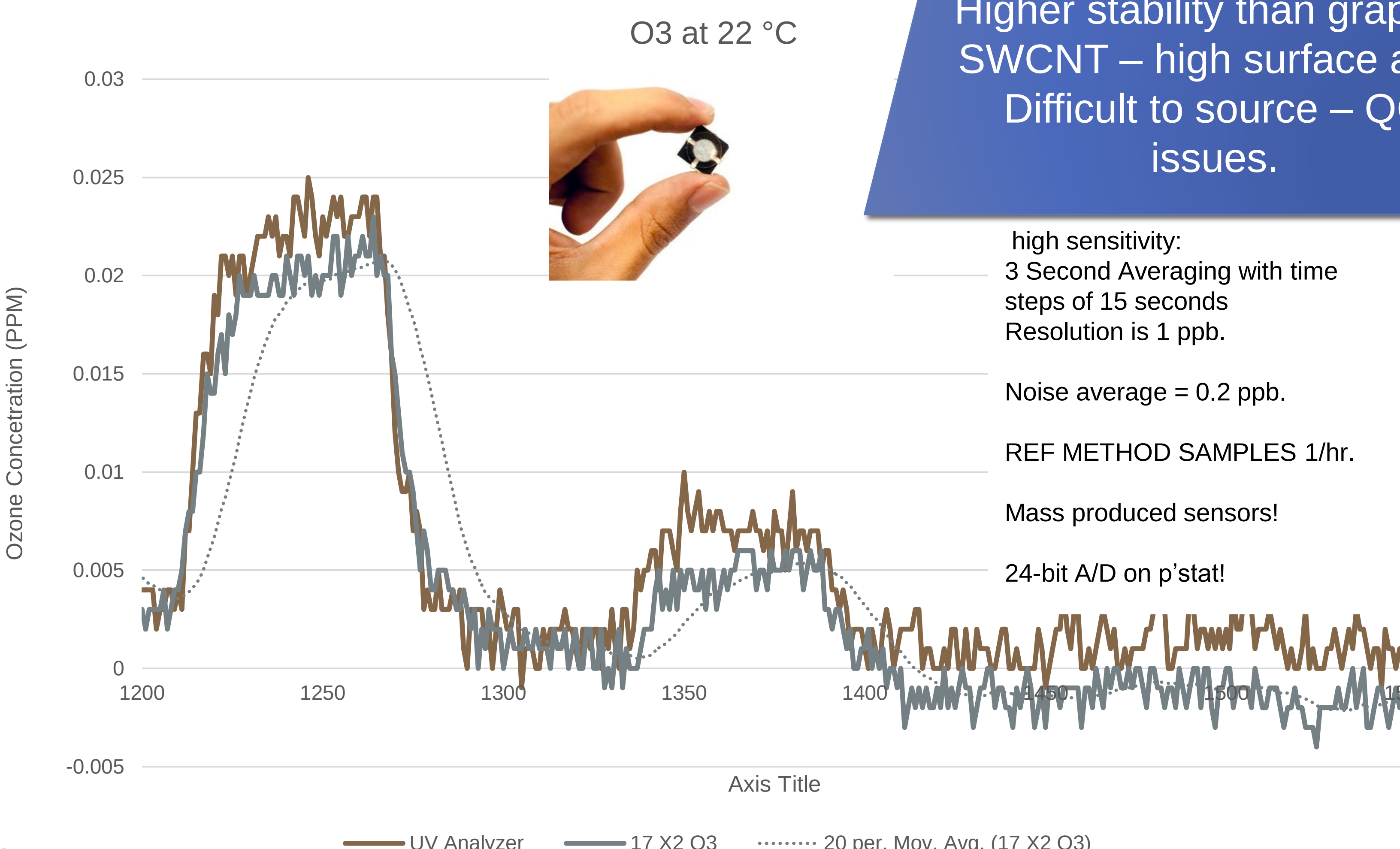
SPEC CNT O3 sensor; trial 2! ppb levels! Ready for manufacture!

CNT is SP2.5 carbon
Higher stability than graphite
SWCNT – high surface area
Difficult to source – QC issues.



high sensitivity:
3 Second Averaging with time steps of 15 seconds
Resolution is 1 ppb.

Noise average = 0.2 ppb.

REF METHOD SAMPLES 1/hr.

Mass produced sensors!

24-bit A/D on p'stat!

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SPECSENSORS

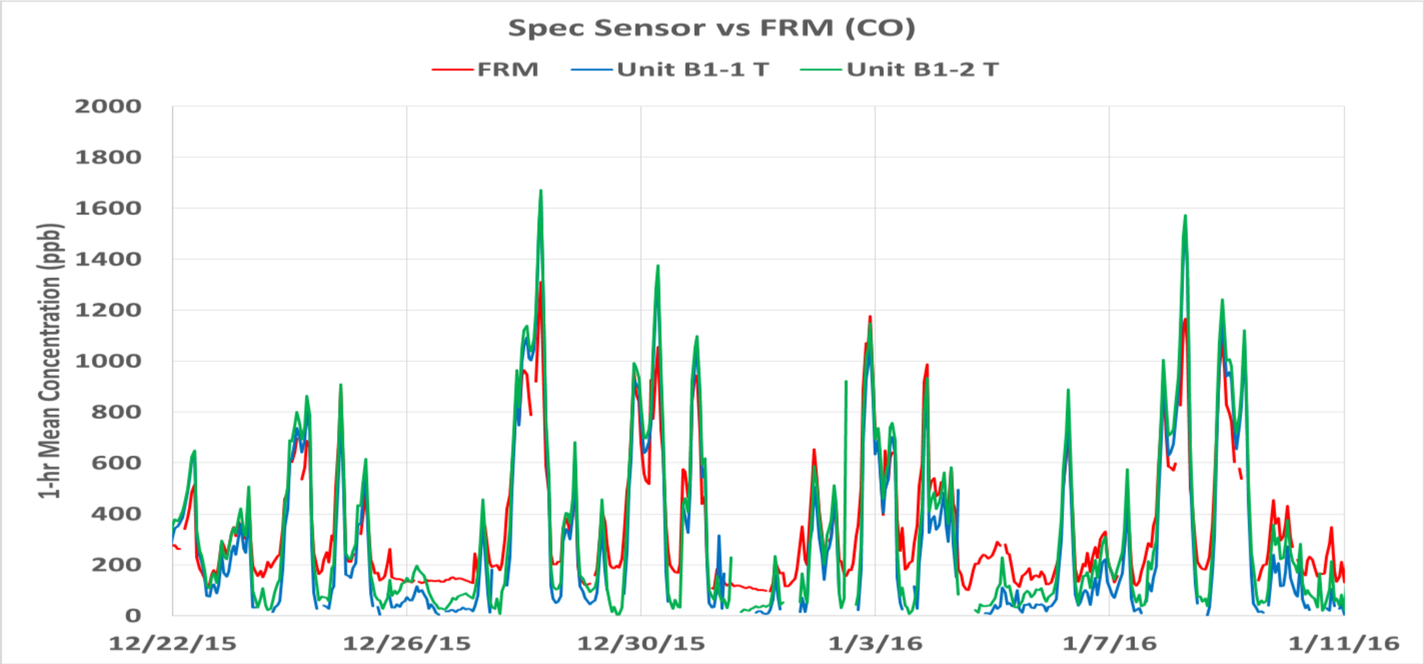
South Coast Air Quality Management District Field Test

The SCAQMD is the air pollution control agency for all of Orange County and the urban portions of Los Angeles, Riverside and San Bernardino counties. This area of 10,743 square miles is home to over 16.8 million people–about half the population of the whole state of California. It is the second most populated urban area in the United States and one of the smoggiest.

SCAQMD is responsible for controlling emissions primarily from stationary sources of air pollution. These can include anything from large power plants and refineries to the corner gas station.

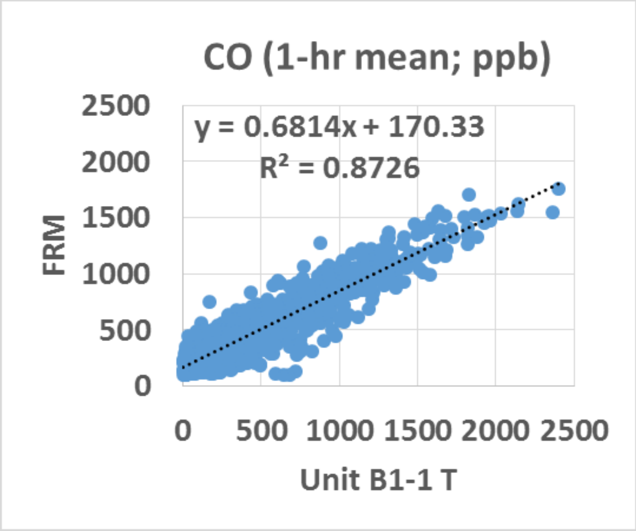
South Coast Air Quality Management District Field Test - CO

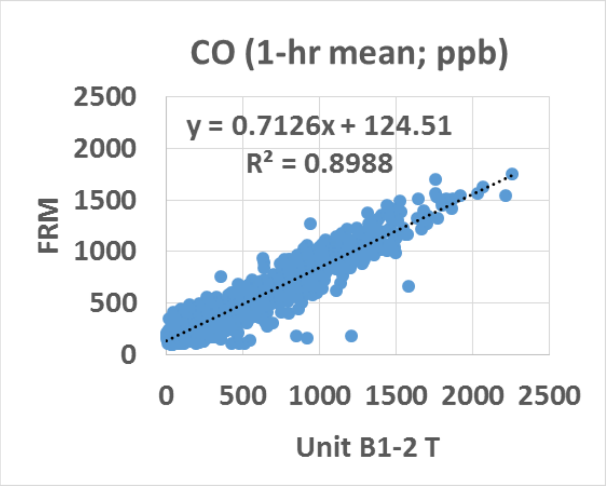
http://www.aqmd.gov/aq-spec/aboutscaqmd



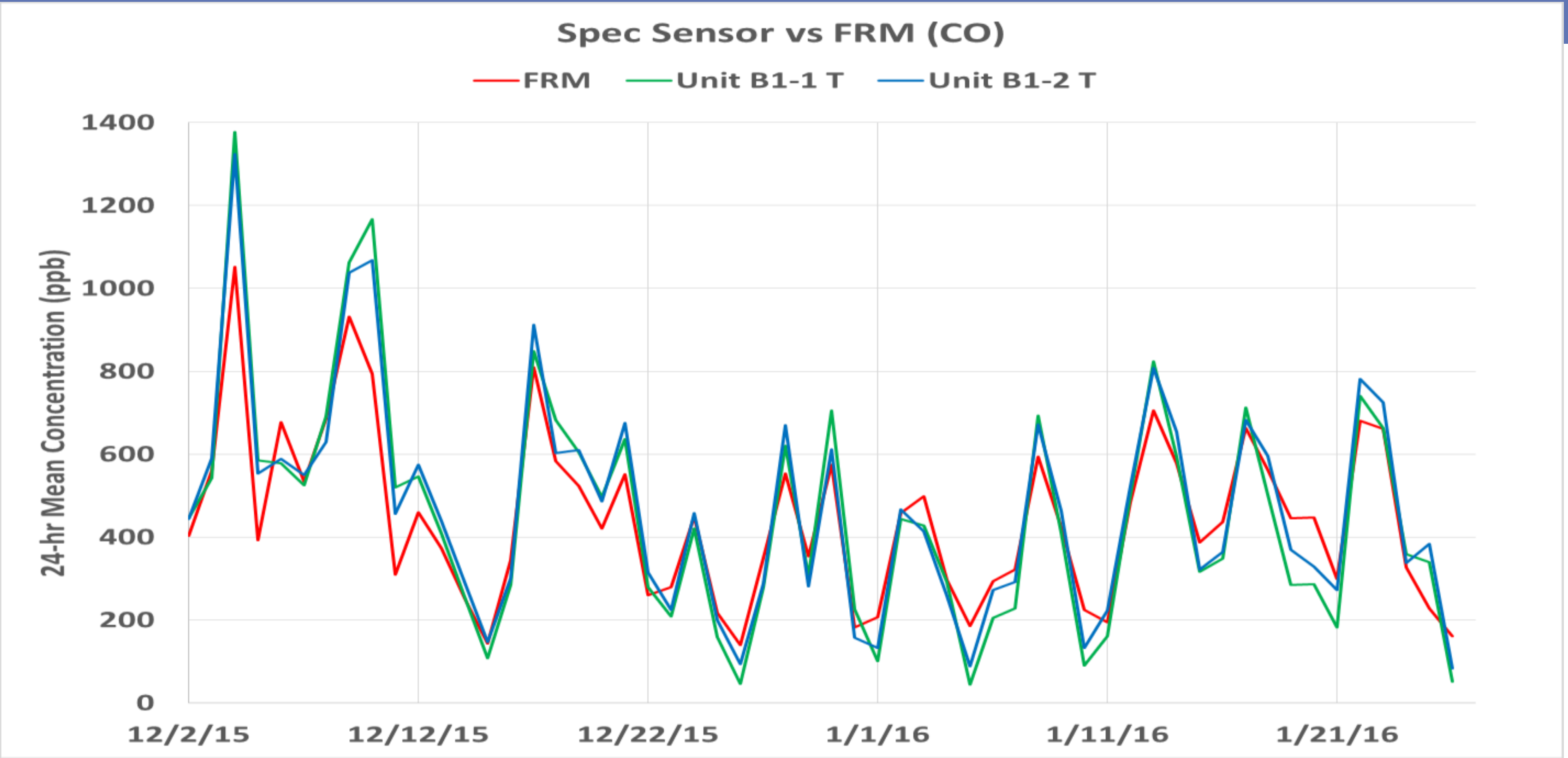
FRM = NDIR

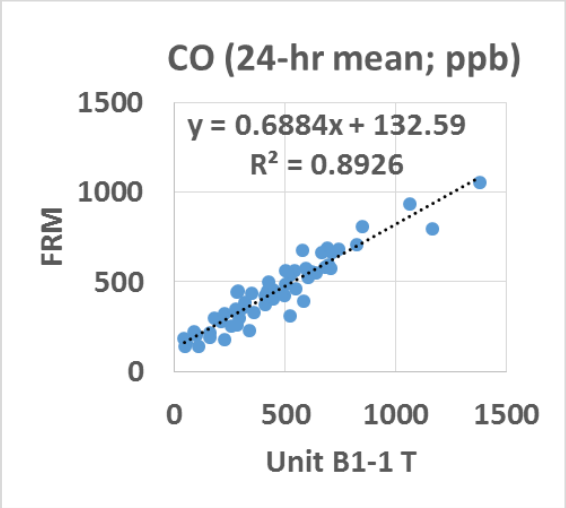
NDIR: cal daily
SPEC: no cal !

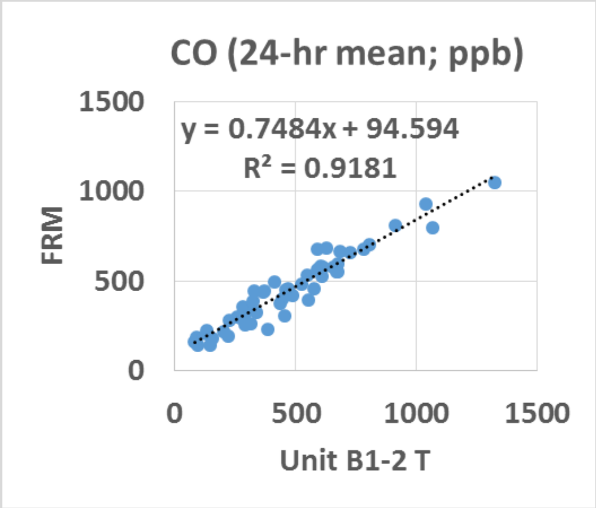




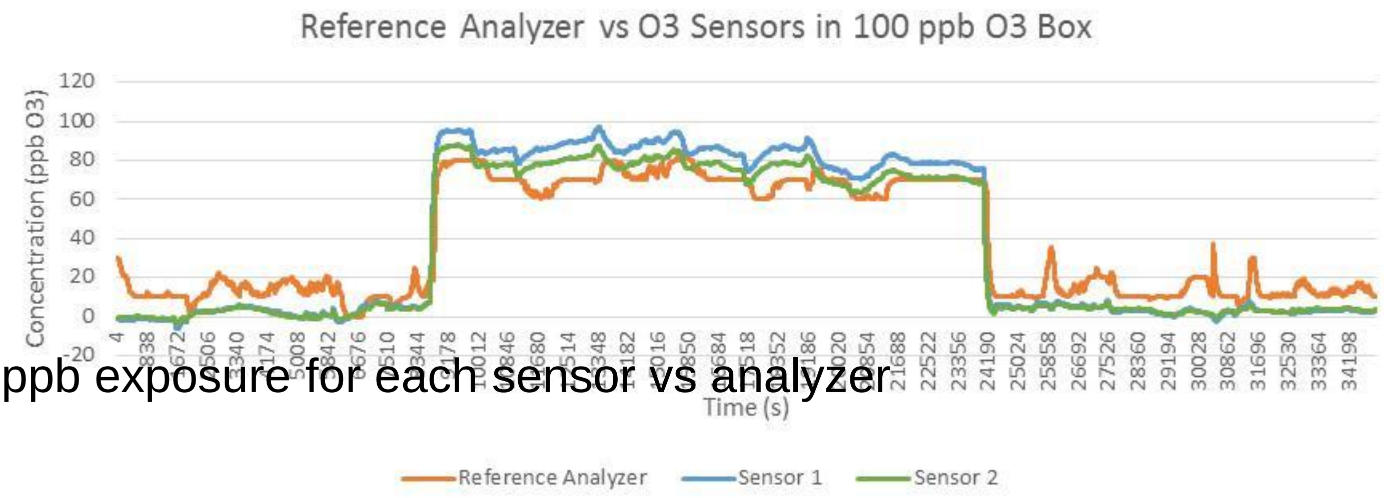
CO sensors correlate well (R2 > 0.87) with the corresponding FRM readings;
can this quality data change the world?


Spec Sensor vs FRM (CO)
FRM
Unit B1-1 T
Unit B1-2 T
24-hr Mean Concentration (ppb)
1400
1200
1000
800
600
400
200
0
12/2/15
12/12/15
12/22/15
1/1/16
1/11/16
1/21/16

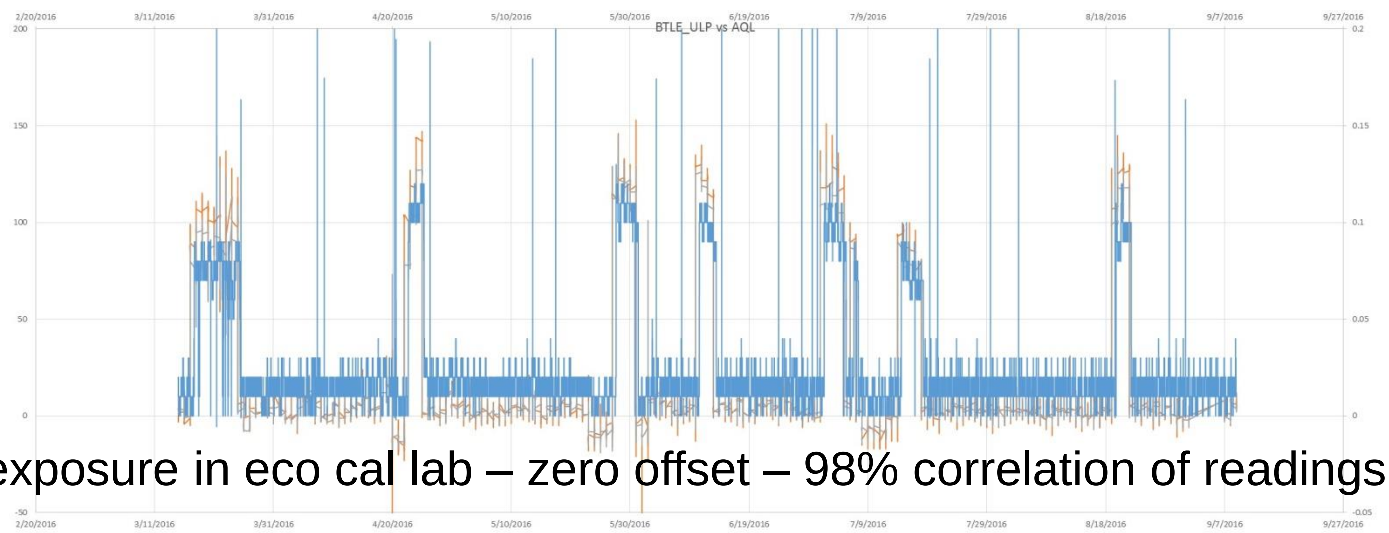

CO (24-hr mean; ppb)
y = 0.6884x + 132.59
R² = 0.8926
FRM
1500
1000
500
0
0
500
1000
1500
Unit B1-1 T


CO (24-hr mean; ppb)
y = 0.7484x + 94.594
R² = 0.9181
FRM
1500
1000
500
0
0
500
1000
1500
Unit B1-2 T

9 months – 2 ea SPEC O3 vs UV in Cal-lab



100 ppb exposure for each sensor vs analyzer



9 months exposure in eco cal lab – zero offset – 98% correlation of readings in room.

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INNOVATIVE SOLUTIONS FOR GAS DETECTION

SPECSENSORS

Summary of the technology

- LEL and ppm level sensing isn't going away, but ppb and sub-ppb sensing is growing in importance – smart cities.
- Amperometric gas sensors (printed) are now validated vs. standard field and reference methods. CO sensor results correlated to NDIR at sub-ppm levels.
- We can measure all gaseous EPA Criteria Pollutants and Alcohol in tiny, wearable, low power packages at relevant health and environmental levels.
- The LOW COST plus low power plus reliability with performance paves the way for wearables and highly distributed measurements!
- Remaining challenge is manufacturing and scaleup – chicken and egg – low cost vs volume order.
- Selectivity and compensation remain an on-going challenge for deployment.
- Packaging and multi-sensor arrays will lead the way!

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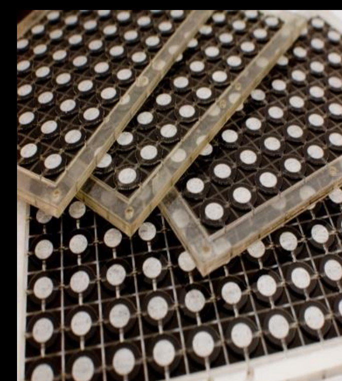
MANUFACTURING
PRODUCTS
[distinct from developing manufacturing]
VS
SENSOR R&D

To understand the need for product manufacturing, must understand the market, distribution, and technology especially where the underlying principles upon which the specifications depend.

FACTORY TOUR

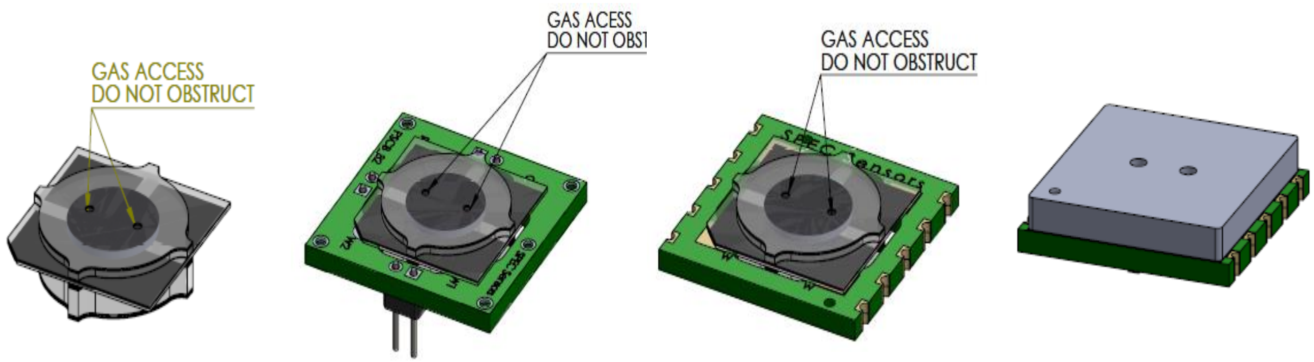


Assembly   Test   Singulation   Packaging

SPEC SENSORS

SPEC Packaging Approach 2015

Sensor Only	Sensor + PCB (P-SPEC)	Sensor + PCB (C-SPEC)	Sensor + PCB + Lid (L-SPEC)

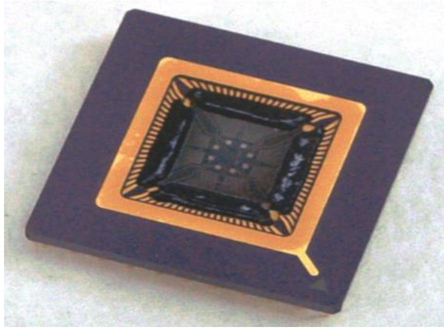


15.0x15.0x3.8mm	20.0x20.0x4.3mm	20.0x20.0x3.8mm	20.0x20.0x4.8mm
15.0x15.0x3.0mm		20.0x20.0x3.0mm	20.0x20.0x4.0mm
10.0x10.0x3.0mm		13.0x13.0x3.0mm	13.0x13.0x4.0mm
10.0x10.0x2.3mm		13.0x13.0x2.3mm	13.0x13.0x3.0mm

New paradigm - enables manufacturing products

Old: technology paradigm

- Sensor R&D
  - By analyte
  - Miniaturize
  - By Technology
    - GC
    - MS
    - Electronic
    - Electrochem.
    - Optical
    - mechanical



New: application focused paradigm

- **Sensor Evolution**
  - **By Architecture**
    - **Low cost, low power**
  - **By Process**
    - **MEMS, plastics**
  - **Integrate/evolve**
    - **Moore's law**
    - **platform**
    - **System**
      - **[AI/com/power/package]**

microprocessor architecture + cmos processes = paradigm for evolutionary devices!
Gas sensor + Printed Semiconductor processes = paradigm for evolution of sensors!

OBSERVATIONS - challenges

- If I had infinite resources I can solve some problems
- If I had infinite time I can solves some more problems
- Continuous management of product evolution.
  - Suppliers, packaging, testing, automation, approvals, …

- The $100M fab!
  - Start with atoms; build catalyst from ground up; nano-materials.
  - Tooling – for 100K, for 10M, for 100M
  - Cost to manufacture – must match market! May not match volume!
    - Question viability of the product – complexity of application
    - Innovation to use existing systems as far as possible [paradigms]
    - Engineering expertise for manufacturing is different.
      - Manufacturing research is different from manufacturing for supply!

Technology Trends

Bio-inspired sensor systems… what can we learn?

Systems approach to functionality…when is it achieved?

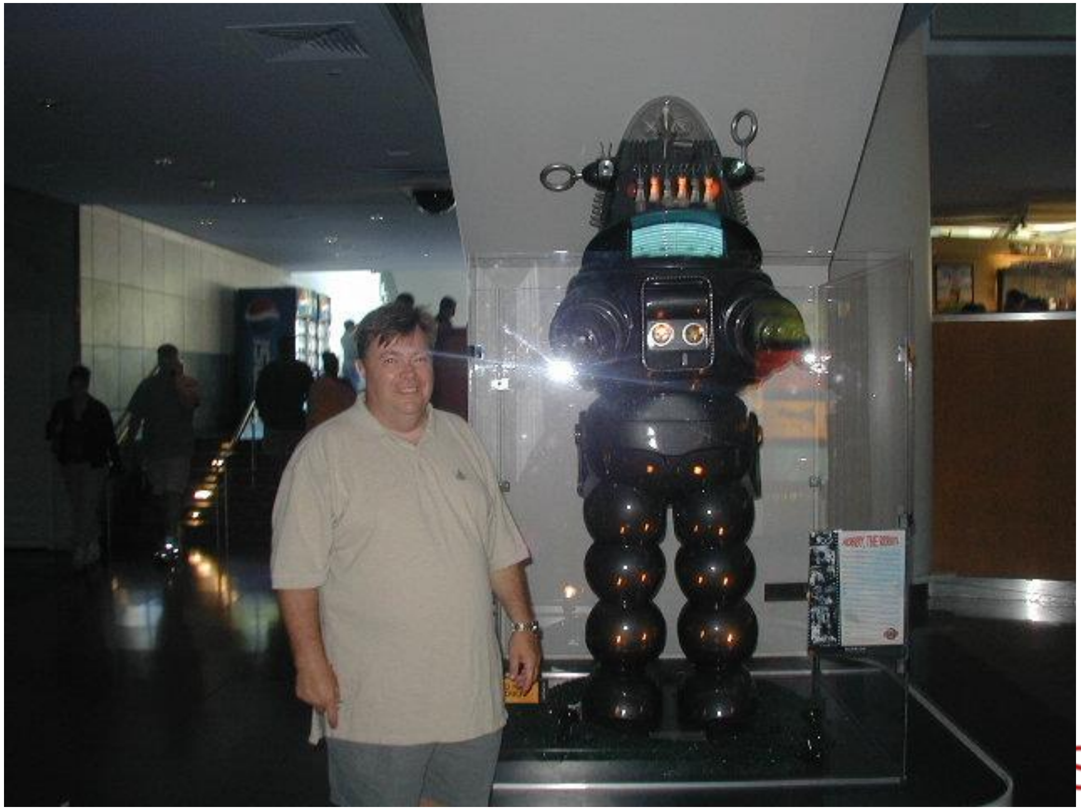
Where do we have to go to achieve the roadmap dreams?

WHAT IS THE SENSOR FAB OF THE FUTURE

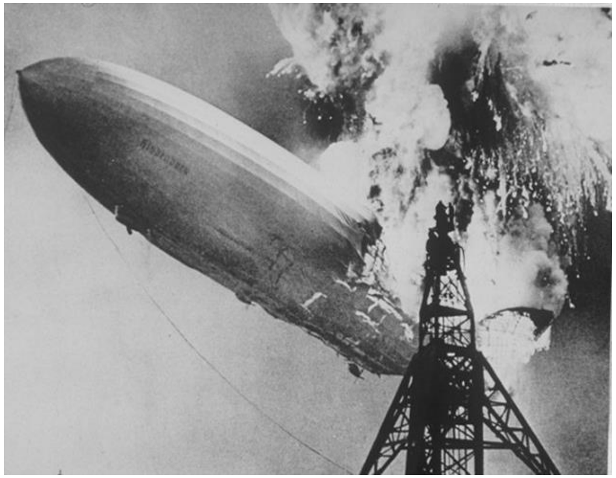
SYSTEMS!

SENSORS +
ELECTRONICS +
ALGORITHMS +
ACTUATOR/DISPLAY

A GDP REVOLUTION!



What we want.



What we fear.

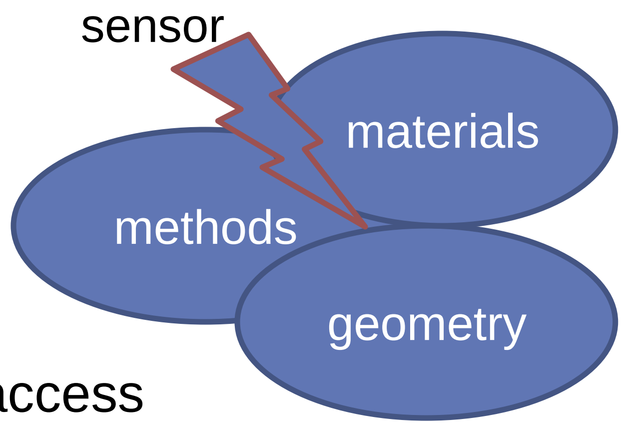
How to see it from the entrepreneur's point of view!

What we get.

How we should View Success!

Challenges for IoT Gas/Personal Sensors

sampling→separation→analysis



- Materials – specific to detection fidelity
  - Sampling system for reactive gases
  - Choice of reactive sensor materials
  - Choice of filter or no filter for interferences
- Geometry – specific to application
  - Sampling system that does not impede gas access
  - Protection against wind, dust, rain, and environment
- Method – smart enough to serve customer need
  - Electronics with sufficient headspace for P, T, RH, [conc] variables
  - Optimized timely sampling of data
  - Feature inclusion firmware and software for application
  - Compensation for T, P, RH, matrix, and app-specific variables.
- Logistics – SIZE, COST, WEIGHT, and SHAPE needed!

Requirements For a Nano-Gas Sensor Fab

** unique structures, processing, & materials!

** large transformation in tooling!

*** INVESTMENT!

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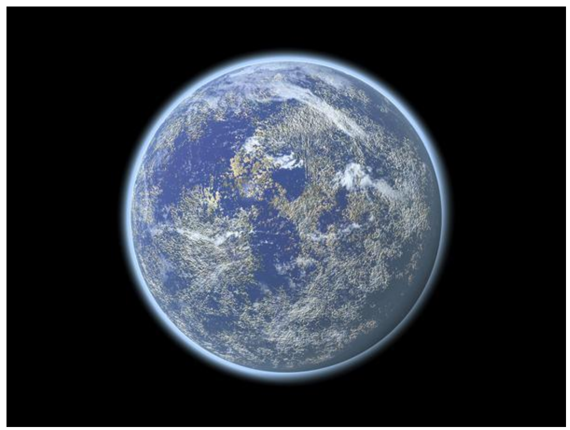
Michael Faraday in his laboratory.

Neither? TBD!!!!

Acknowledgements

National Science Foundation, Award No. 1058563 (NSF SBIR Phase I and II), supplemental grants (Phase IIB and TECP) and **Phase III (SPEC Sensors/KWJ Eng. Inc.)** National Institutes of Health, Grant No.1R43ES019385-01
National Institutes of Health, Grant No. 1R43ES021676-01, 2R44ES021676-02 (NIH NIEHS SBIR Phase I & II)



https://www.indiegogo.com/projects/sparrow-wearable-air-monitor-by-eco-sensors#/

SPEC SENSORS

KWJ ENGINEERING INC
INNOVATIVE SOLUTIONS FOR GAS DETECTION

OUR AIR IS A PRECIOUS AND LIMITED RESOURCE!

Vital to our survival! Knowledge from Global IoT air quality networks, with “0” power low-cost SPEC sensors, will enable changes in human/social behavior!

Thank you from all of us!

KWJ ENGINEERING INC — INNOVATIVE SOLUTIONS FOR GAS DETECTION

SPECSENSORS