# SHARED EXPERIENCES IN GAS DETECTION - NEW SOLUTIONS FOR OLD PROBLEMS

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# OUTLINE

**Landscape**
Familiar applications & detection principles

**Requirements**
Unmet customer needs

**Evolution**
Paths to better solutions
*Examples –* *Thermal Conductivity*
*NDIR*
*Electrochemical*

**Closing Comments**

A SHORT OVERVIEW

# APPLICATIONS

| Oil & Gas Exploration | Chemical & Petrochemical | Power & Utilities | Water & Waste | Emissions | Environmental | Medical |
|---|---|---|---|---|---|---|







**Key measurands**
- Oxygen
- Toxics – CO, $H_2S$, $SO_x$, $NO_x$…
- Flammables - $C_xH_y$
- Environmental – $CO_2$, $CH_4$, VOCs…

**Fixed / portable applications**
- Different constraints
- Size, cost and power

**Typical users**
- Workers in hazardous zones
- Process & Emission controllers
- Legislators & enforcement

**Drivers for new applications**
- Evidence of long term harmful effects
- Global warming
- Tighter legislated limits
- Demand for connectivity
- Public concern & engagement



**MANY CRITICAL LIFE SAFETY APPLICATIONS IN CONSERVATIVE, REGULATED INDUSTRIES**

# EXAMPLES OF PHYSICAL & CHEMICAL METHODS

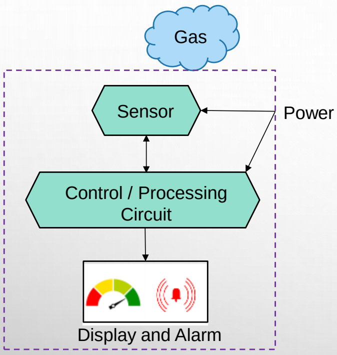
| | |
|---|---|
| **Optical (Direct)** | IR, UV or Visible Absorption<br>Photoacoustic<br>Raman |
| **Optical (Indirect)** | Colourimetric<br>Fluorescence Quenching<br>Chemiluminescence |
| **Thermal Conductivity** | |
| **Mass** | Surface Acoustic Waves<br>Bulk Acoustic Waves<br>Mass Spectrometry |
| **Ionisation** | Ion Mobility<br>Flame Ionisation<br>Photoionisation |
| **Paramagnetic** | |

| | |
|---|---|
| **Combustion** | Exothermic Reactions<br>Flame Effects |
| **Surface Electrical Interactions** | Metal Oxides<br>Carbon Nanotubes<br>Field Effect Transistors |
| **Bulk Interactions** | Dimensional Changes<br>Electrical Effects |
| **Electrochemical Reactions** | Amperometric<br>Potentiometric<br>Consumable / Non-consumable |
| **Ion Selective Electrodes** | |
| **Biosensors** | |

Well understood physical & chemical properties
Some known & exploited for >100 yrs

**WIDE RANGE OF GAS PROPERTIES CAN BE EMPLOYED**

# THE IDEAL GAS DETECTOR?



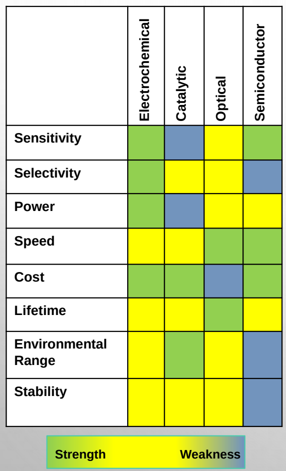

**SAFE**
**SENSITIVE**
**RELIABLE**
**REVERSIBLE**
**LONG LIFE**
**SMALL, LIGHT & RUGGED**
**LOW COST**
**LOW POWER**
**SPECIFIC**
**ENVIRONMENTALLY STABLE**

**The observation of an effect due to gas is *only the beginning*….**

**Developing a viable detection method can be a long and challenging journey …**

**MANY COMPETING REQUIREMENTS**

# TECHNOLOGY vs REQUIREMENTS




**No solution meets all requirements in all markets**

- Evolutionary, incremental improvements
- But many issues remain
- Successful products are well matched to real user experience
- Manufacturability / reproducibility is key

**Evolving expectations**

- Signal → Information
- Reliability compatible with everyday products (cars, phones)
- Customers expect technology maturity to deliver benefits ($)

**Technical and practical shortcomings & new markets drive interest in alternatives**



**UNMET CUSTOMER DEMANDS IN EXISTING AND EVOLVING MARKETS**

# EVOLUTION

**Clearly Identified Need**
- Often commercial….
- Protection of plant, production and people

**Core Principle(s)**
- Initial inventive 'spark'
- Application of physical chemical 'effects'

**Initial Implementation**
- Better than alternative - but with shortcomings
- Poor quality components, materials & manufacturing

**Evolving Expectations**
**Customers are demanding!**
- Cheaper, longer life, low power
- Reliability → no downtime

**New Markets**
**Require more/better data**
- Greenhouse gases
- Urban pollution

**Growing Capabilities**
**Sharing advances in other technologies**
- Microelectronics
- Processing (local / cloud)

**Unmet Customer Needs → Innovation**
- Improved sensitivity & specificity
- Analog signal → digital Information → onboard compensation, self test & diagnostics
- Sensor networks – benefits of scale



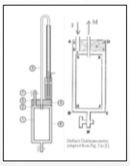
**TECHNOLOGY SHARING & MATURITY TO DELIVER USER BENEFIT**

# EXAMPLE – THERMAL CONDUCTIVITY

First studied & used in 1840 (Fourier, Joule)
Earliest form of practical gas analysis based on physical principles

Hydrogen purity & leakage in airships

'Firedamp' (Methane) measurement in mines



Diathermometer (1872) Stefan

Katharometer (1957) Stuve

Tankscope (1970s) MSA

Bead methods (1970s) EEV & others

**However –**
- All components in the mixture contribute to aggregate response
- Not specific – best for binary mixtures
- Hard to measure gases with Tc close to air

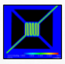
Limits use in demanding applications

**HOW CAN THE METHOD EVOLVE?**

# EXAMPLE – THERMAL CONDUCTIVITY

**Recognise** that dynamic thermal properties demonstrate subtle variations between gases
- Differential scanning calorimetry converts gas properties → electrical signal
- Rapidly heat / cool a body and measure response
- Capture and analyse data / Correct for interferences (T, P, RH affect Tc)

**Si micromachined (MEMS) hotplates**
Rapid heating/cooling
Long life (15+ years)
Small size
Low power (<30mW avg)

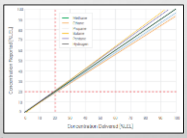



**Miniaturised powerful processing capability**
Converts *raw* signal to *useful* information
Algorithms exploit detailed knowledge of gas properties
Multi-gas accuracy in real-time


**Self-test & calibration**
Long term unattended operation
No calibration

**Environmental compensation**
Utilise specialised sensors for other measurands
Improved accuracy in varying environments

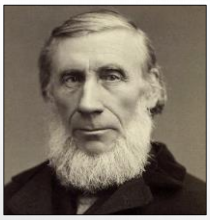
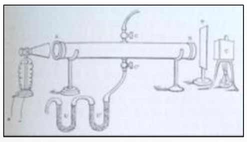
NevadaNano

*nevadanano.com*

**COMBINE CORE SCIENCE WITH STATE-OF-THE-ART TECHNOLOGIES SHARED WITH OTHER FIELDS**

# EXAMPLE – NDIR

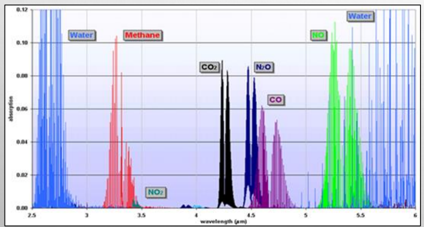
Tyndall's apparatus (1865)

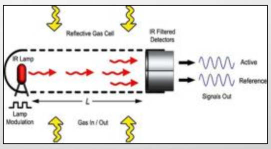
**Source –**
- Soot covered cube filled with boiling water
- 100C Black body source (5-10µm)

**Detector –**
- Thermocouples in series – 'Thermopile'
- Galvanometer to read output

**Cell windows –**
- Rock salt

Able to detect the absorption of IR radiation eg by ethylene in the cell as a function of pressure
Measured absorptions of many other gases




**Source properties are critical –**
**Useful** optical power (at right wavelength) impacts sensitivity-pathlength trade-off

**PATHLENGTH TENDS TO LIMIT PRACTICAL PACKAGE SIZE**

# OPTICAL SOURCES FOR NDIR

**Thermal sources (filament bulbs, MEMs hotplates)**
- Low cost
- Broad band emission – optically inefficient
- Relatively slow modulation and high power - 10s-100s mW
- Use in portable and battery powered applications challenging





**Photonic sources (LEDs, lasers)**
- Faster modulation
- Narrower band emission - more efficient - <1 mW feasible
- But much more expensive




**Availability**
- Initial work used versions developed for communications wavelengths
- Has taken many years / attempts for dedicated photonic sources to become available
- Economics for low-cost gas detection still problematic

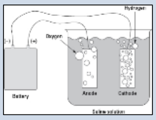
**SELECTION IS HIGHLY APPLICATION DEPENDENT**

# EXAMPLE – ELECTROCHEMICAL

**Faraday** – fundamental electrochemistry and electrolysis experiments - 1800s
Amount of chemical change or decomposition in an electrochemical reaction is proportional to the quantity of electricity
**A means of 'measuring' chemical reactions of gases**

**BUT!**

Turning this….



Into this….

… requires a lot of technical innovation…

…drawn from a surprisingly wide range of fields…

**Catalysts**
*Apollo space program*

**Packaging**
*Battery techniques*

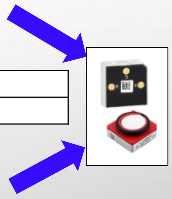
**Materials**
*Electrode membranes*

**TECHNOLOGY SHARING ENABLES VIABLE SOLUTIONS**

# AN ELECTROCHEMICAL TIMELINE

$O_2$

| Life (mo) | 3→9 | 18 | >24 | >60 |
|---|---|---|---|---|
| Type | Pb battery | | | Pt fuel cell |



CO

| Volume ($mm^3$) | 22 | 11 | 5 | 1 |
|---|---|---|---|---|

| Analogue<br>No correction or self-test<br>Requires A/D conversion | Digital<br>Increasing capabilities<br>Self check & compensation |
|---|---|

CITY Dräger **Single/Few → Many suppliers** More competition drives innovation & cost reduction alphasense AMETEK MEMBRAPOR

**LONG TERM EVOLUTION BASED ON COMMON CORE TECHNOLOGY**

# EXAMPLE – ELECTROCHEMICAL NETWORKS

**Poor Urban Air Quality is a global concern…**

**Traditional approach**
Complex monitors providing traceable measurements
Few stations @ $100k (plus complex skilled maintenance)
Lacks spatial coverage and real time feedback for population

**Alternative?**
Multiple low cost sensors - localised granularity of data - real time pollution tracking
Data fusion with innovative algorithms to mitigate weaknesses of individual devices

Autonomous operation – faster, easier, lower-cost calibration
100s stations @ $3k *eg AQMesh, Clarity, Breathe London*

Provides critical data for policymakers AND local residents

**Critically dependent** on communication and processing infrastructure

**Not developed for sensing** - borrowing technology from other fields

**VALUE DELIVERED BY NETWORK IS GREATER THAN SUM OF PARTS**

# CLOSING COMMENTS

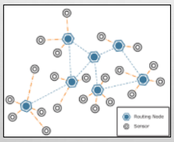
**History**
'Traditional' gas detection technologies >150 years - 'Practical' sensor designs >50 years
Many are still key for users – despite weaknesses

**Evolution**
Most developments incremental rather than disruptive

**Multidisciplinary**
Physics + Chemistry + Materials + Engineering + Manufacturing + Computing ….

**Sharing**
Benefit from other fields

**Connectivity**
Shared data
Cloud processing – A.I.
Increase information content
Use beyond the instrument




**Miniaturisation**
More sensors in more places
Granular data

**IMPROVED SOLUTIONS IN NEW & EXISTING APPLICATIONS**

# ACKNOWLEDGEMENTS

To numerous colleagues over many years….

NCB – people will always need coal: 1978 - 1994

City Technology / Honeywell: 1994 - 2021

GASG: 1993 - today

## Thank you!

Picture credits –

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