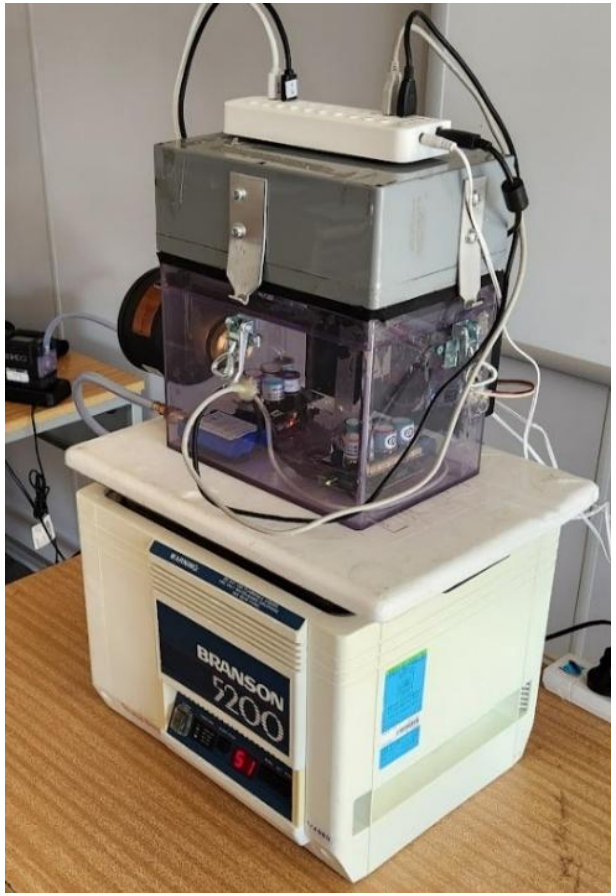
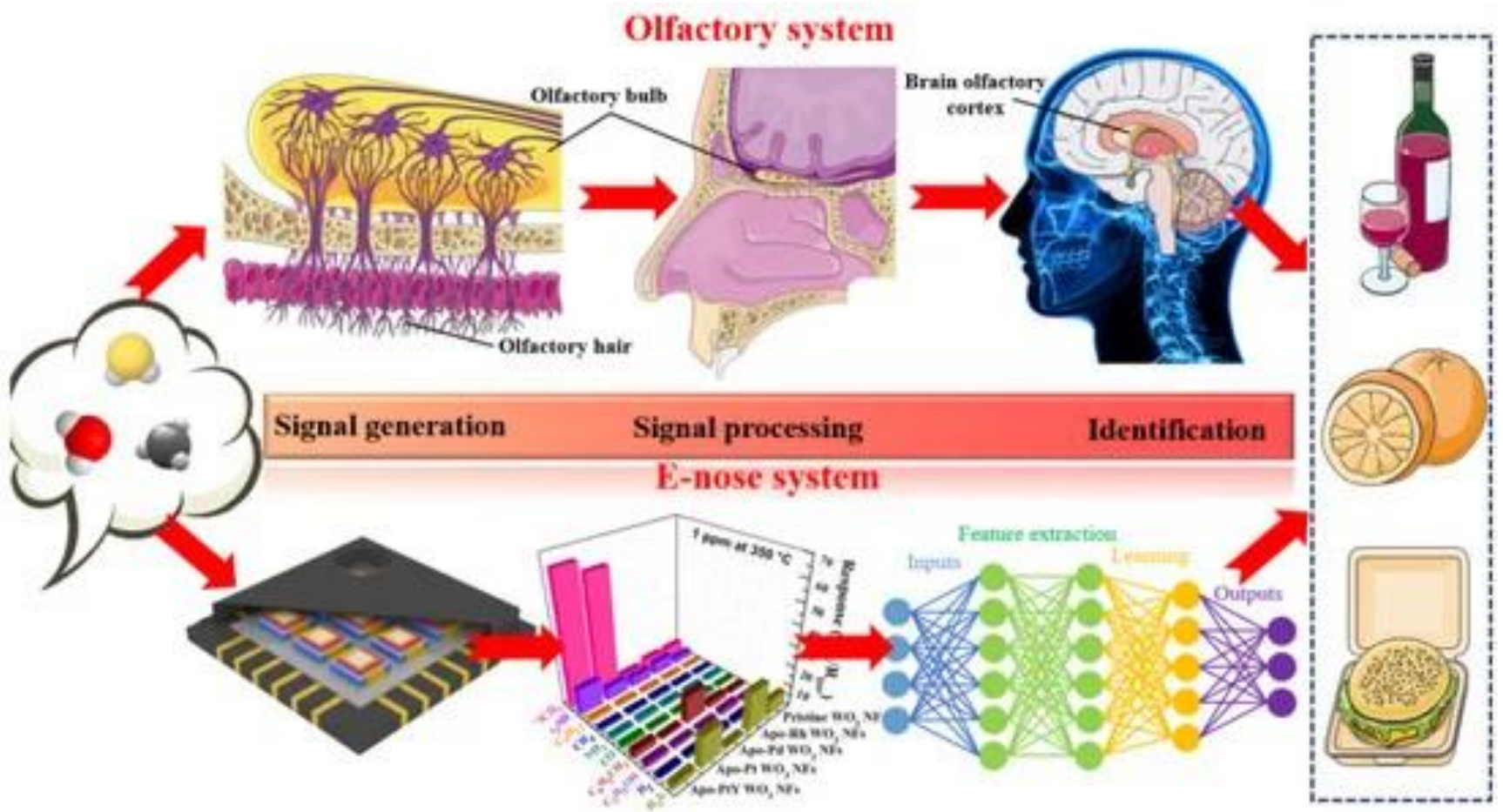
A Low-Cost Hybrid Electronic Nose for the Detection and Classification of Explosive Vapours



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Australian Defence Force

Schematic Diaram of Human Olfaction And E-Nose



Source: Zhai et al., 2024

Use of Commercially Available Gas Sensors and AI Integration for Explosive Detection and other applications

Temperature, light, infrared, ultraviolet radiation, and other mechanisms explosives will decompose into products such as, CO_2, CO, NH_3,**NO**, **NO_2**, **H_2O_2, N_2**, **acids, aldehydes, ketones…**

Low-cost, accessible alternative by integrating commercially available gas sensors with artificial intelligence (AI) for real-time explosive detection.

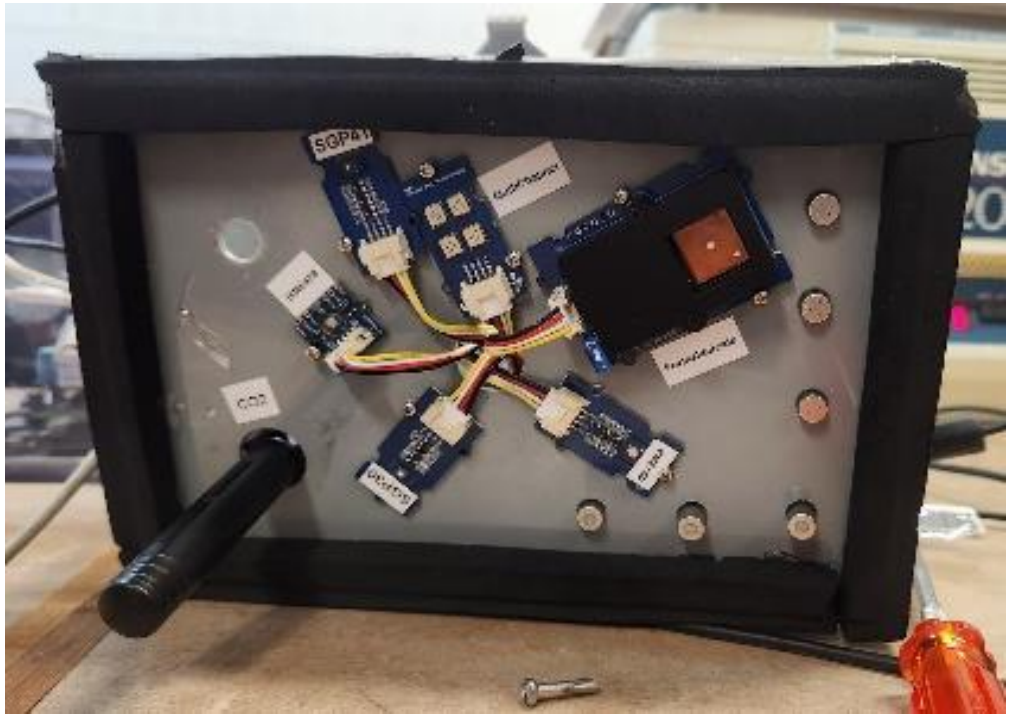
Identify readily available commercially available Gas Sensors

(NO_2, O_2, NO, CO_2, CO, NH_3, H_2, SO_2, H_2S, VOC…)

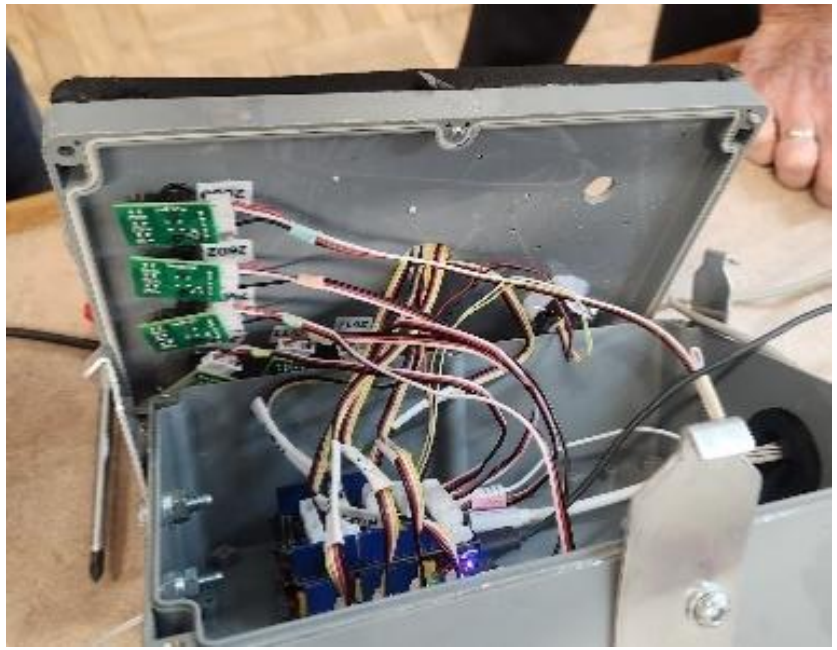


Broader Applications: - food safety, where sensors could detect spoilage or contamination,

- environmental monitoring



A hybrid array combines broad and selective channels



27 sensing elements

Distributed across multiple boards, with environmental and gas-response channels.

BROAD RESPONSE

MOS and MEMS

SGP30 · BME688 · SGP41 · TGS2602 · multichannel modules

TARGETED RESPONSE

Electrochemical channels

SFA30 (HCHO) · NO-A4 · OX-A431 · 4-H_2S-100

Why combine them?

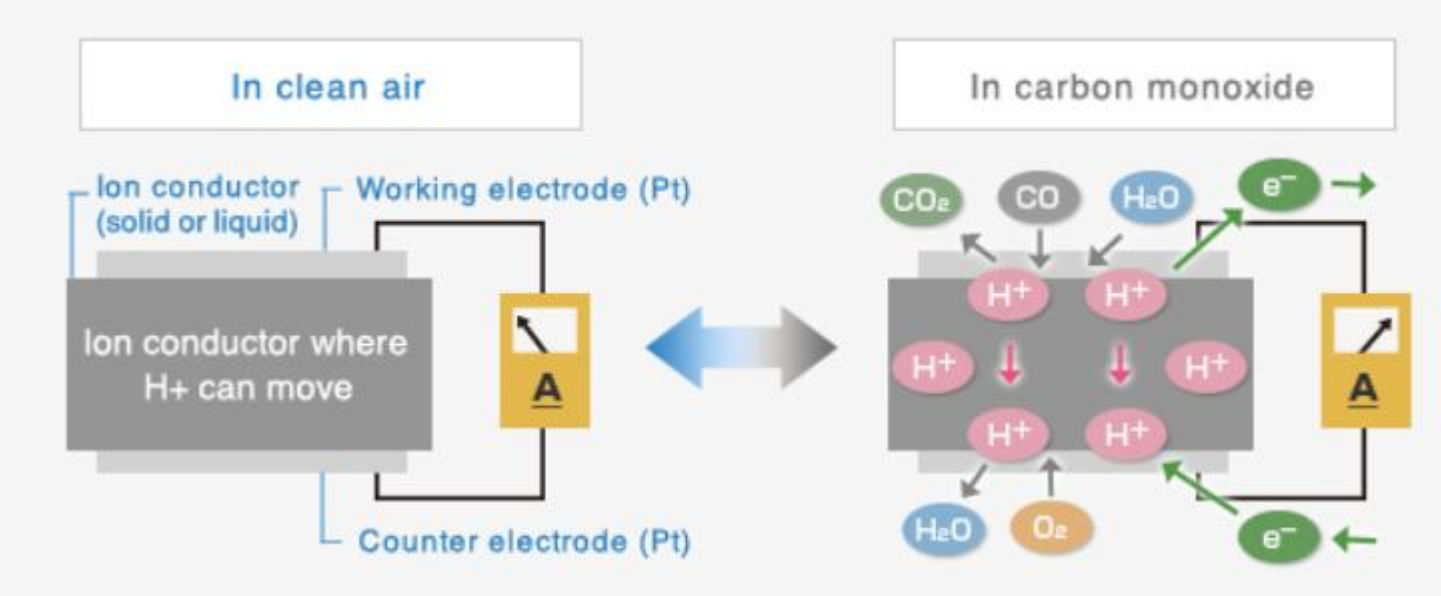
Broad sensitivity supplies pattern coverage; targeted channels add complementary chemical cues.

Electrochemical Sensors

- Detect change of signal caused by electric currents or electric potential through electrodes. Use **electrodes + electrolyte.**

- Involves chemical reaction (Redox reaction) of the explosive molecules or their decomposition product.

- High selectivity, designed for specific gases.



Source:https://www.figarosensor.com/technicalinfo/principle/electrochemical-type.html

Metal Oxide Sensors (MOS) and MEMS (micro-electro-mechanical systems)

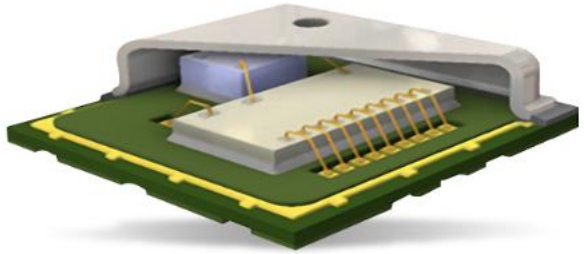
- The sensing layer is typically a semiconducting metal oxide such as: Tin dioxide, Zinc oxide, Titanium dioxide.

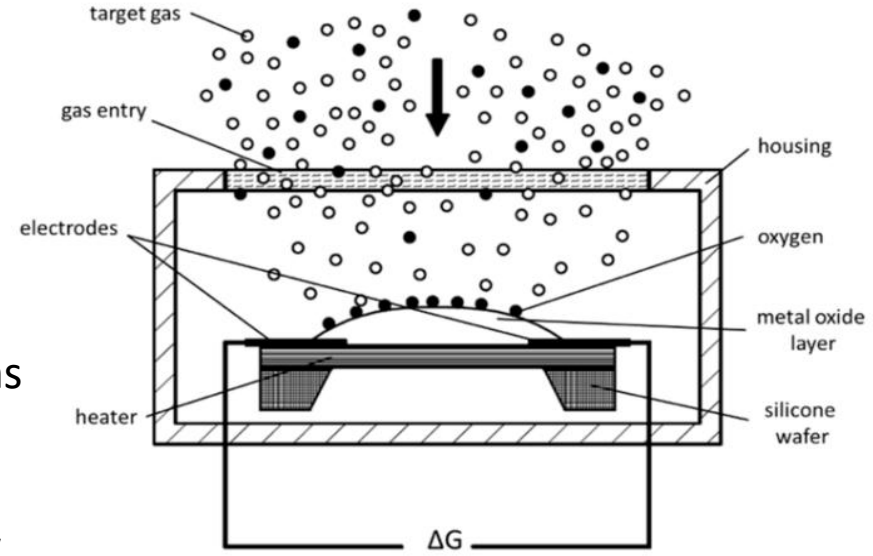
- These materials are heated (usually 200–400 °C).

- In clean air Oxygen adsorbs onto the surface.
  It captures electrons → forming O^-, O_2^- species.
  This creates a depletion layer, increasing resistance.

- Reducing gases (e.g., CO, CH_4, H_2):React with adsorbed oxygen
- Release electrons back → resistance decreases
- Oxidizing gases (e.g., VOC, NO_2):Withdraw more electrons → resistance increases

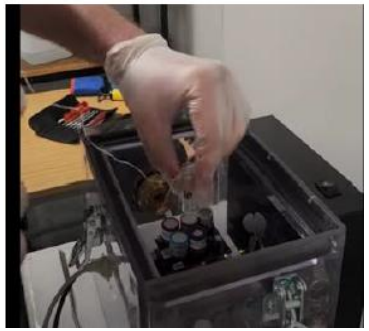
- While highly sensitive, they often have limited selectivity

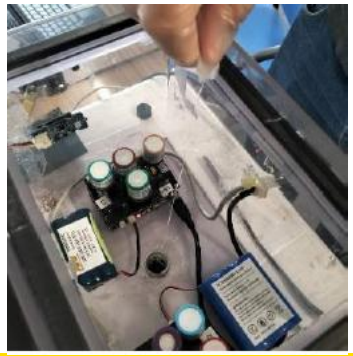




Controlled headspace tests used a fixed thermal protocol







TEST CONDITIONS

01 **Baseline** — **15 min**

Background reference before sample exposure

02 **Exposure** — **15 min**

Milligram-scale sample; water bath at 50 °C

03 **Purge** — **5 min**

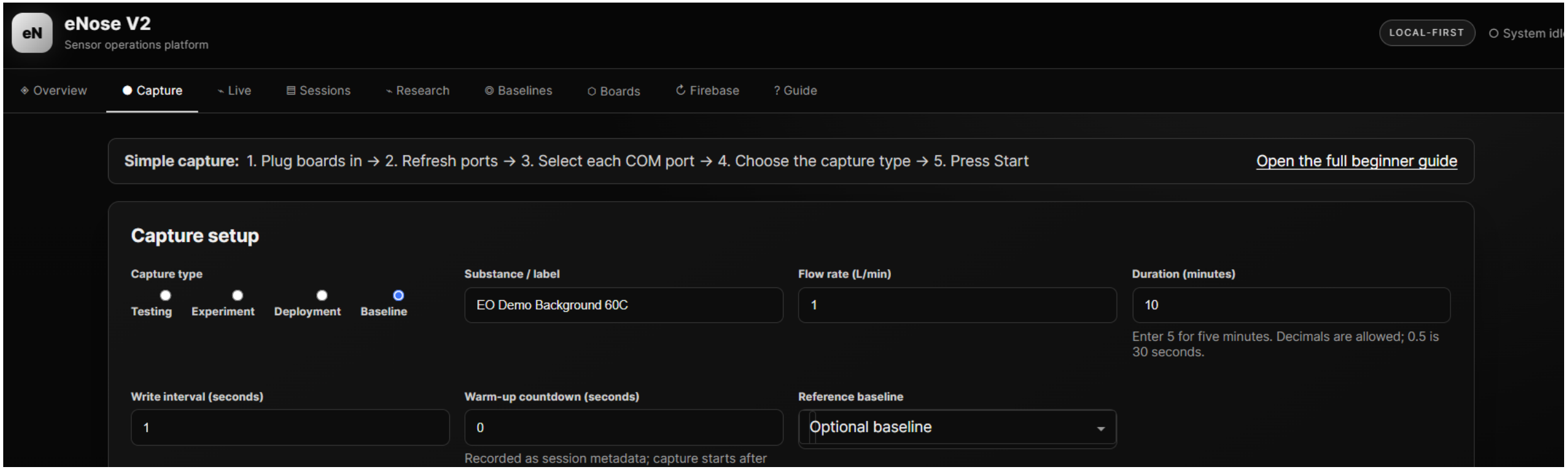
Between runs, followed by baseline checks

Signals sampled at 1 s intervals and analysed as steady-state sensor features.

Heating was used to increase vapour availability in this controlled bench-top study.

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E-nose User Interface



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Tested Explosives



Explosive	Typical classification	Vapour pressure (Pa)	Notes / identifying features
TATP (triacetone triperoxide)	Primary high explosive (organic peroxide)	2.4×10^{-4}	White crystalline solid with an acetone-like odour. Extremely sensitive to friction and impact, which becomes more sensitive as it ages and dries. Very high sublimation rate. Commercial use: none.
HMTD **(hexamethylene triperoxide)**	Primary high explosive (organic peroxide)	3×10^{-7}	White crystalline solid. Extremely sensitive to friction and impact, which becomes more sensitive as it ages and dries. Much lower volatility than TATP and little odour. It breaks down at room temperature. Commercial use: none.
MEKP (methyl ethyl ketone peroxide)	Organic Peroxide (commercial initiator)	1.84×10^{-3}	Oily viscous liquid, normally colourless. Very sensitive to heat, shock, and friction. Extremely volatile and will evaporate rapidly. MEKP can undergo self-decomposition, releasing heat and volatile decomposition products that risk forming a flammable vapour cloud. Commercially used in plastic manufacture.
Mercury Fulminate	Primary explosive (metal fulminate)	Negligible	White to grey crystalline material that darkens with age/light exposure and will reduce in strength. Of note, sample used was close to brown in colour. Very sensitive to impact and friction. Historically used in percussion caps.
Lead Azide	Primary explosive (metal azide)	Negligible	White to powdery cream coloured solid. Common detonator explosive. Sensitive to shock and friction; forms hazardous heavy-metal contamination.
Urea nitrate	Improvised high explosive (salt-type)	3.94×10^{-5}	White to off-white crystalline, highly water soluble, usually odourless, may retain residual acidity (vapour hazard). Commercial use: none. Treat as hazardous.
ETN (erythritol tetranitrate)	Secondary high explosive (nitrate ester)	7.7×10^{-4}	White crystalline, similar properties to PETN, sensitive to heat (burns unconfined) and more sensitive to shock/friction than many secondary explosives. Can detonate if heated on foil.
Nitroglycerin (NG)	Secondary explosive (but highly sensitive in pure form)	4.40×10^{-2}	Oily/viscous, forms immiscible layer with reaction acids, may burn rapidly on cellulose; inhalation hazard (headache, dizziness, low blood pressure). Commercial NG is usually desensitised for safe use.
RDX	Secondary high explosive (nitramine)	1.33×10^{-7}	White crystalline, generally stable in storage, will burn if heated unconfined; commonly encountered in military explosives and industrial formulations.
R-Salt (CTMTNA)	Improvised/secondary (salt-type explosive)	No reliable VP found in open literature	Yellow crystalline powder, relatively stable in storage but incompatible with other explosives (store separately); toxic and carcinogenic. Listed precursors: hydrochloric acid (or dilute sulfuric), hexamine, sodium nitrite. Commercial uses: none. Treat as hazardous and contaminant-sensitive.

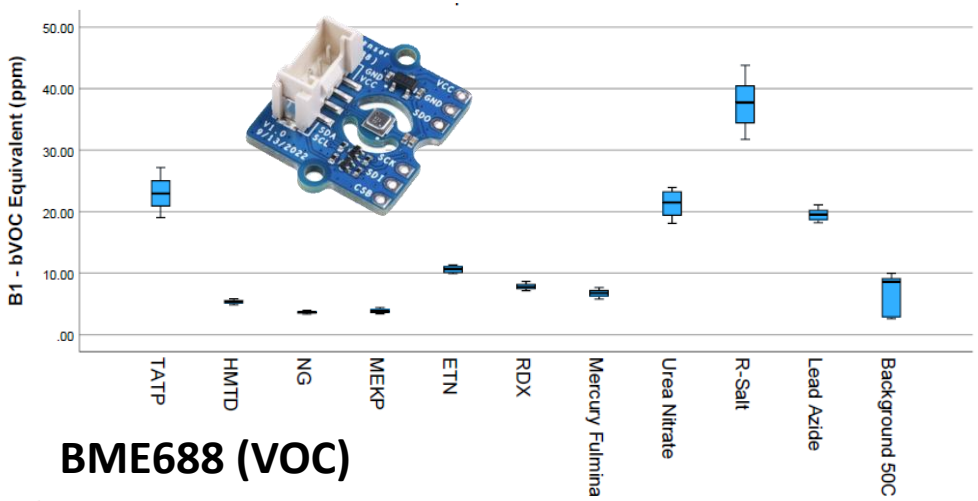
Tested Explosives



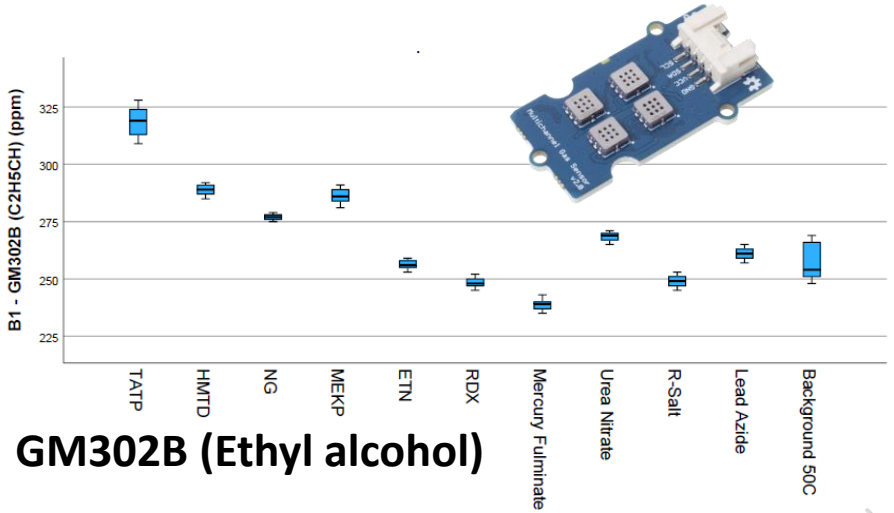
Explosive Class	Example Compounds	Typical Vapour Pressure	Key Volatile/By-products
Nitramines	RDX	ppt–ppq	NO_2, NO, HCHO
Nitrate Esters	NG, ETN	ppb–ppm	NO_x, CO, alcohols
Oxidiser Salts	Urea Nitrate, R-Salt	Negligible (non-volatile)	NH_3, NO_2, CO_2, H_2O
Peroxides	TATP, HMTD, MEKP	ppb–ppm	C_3H_6O, CO_2 , CH_3OH, CH_3COOH $C_4H_8O_2$,
Primary Explosives	Mercury Fulminate, Lead Azide	Negligible (non-volatile)	N_2, CO, CO_2

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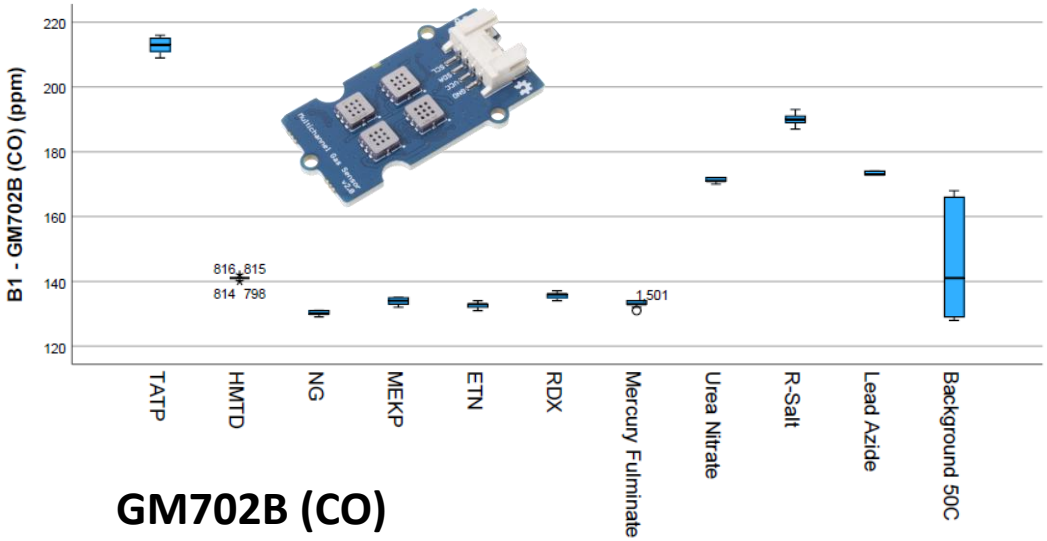
Univariate Analysis of E-Nose Experimental Results



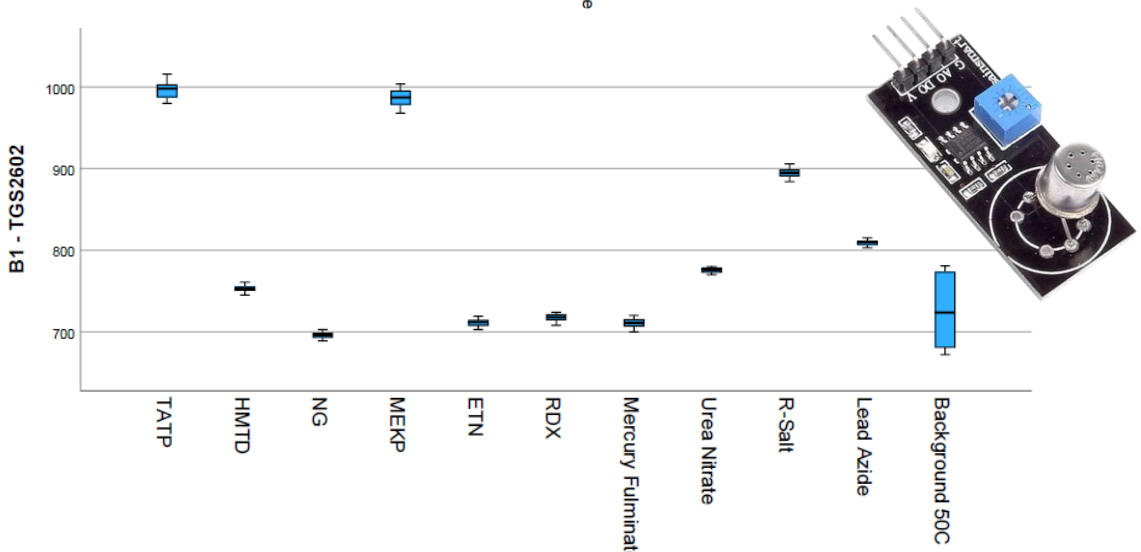
BME688 (VOC)



GM302B (Ethyl alcohol)



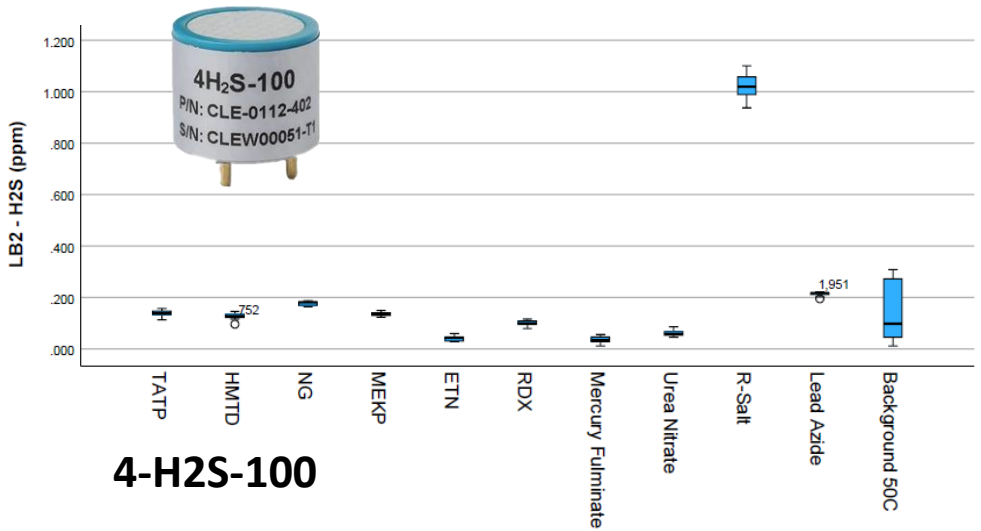
GM702B (CO)



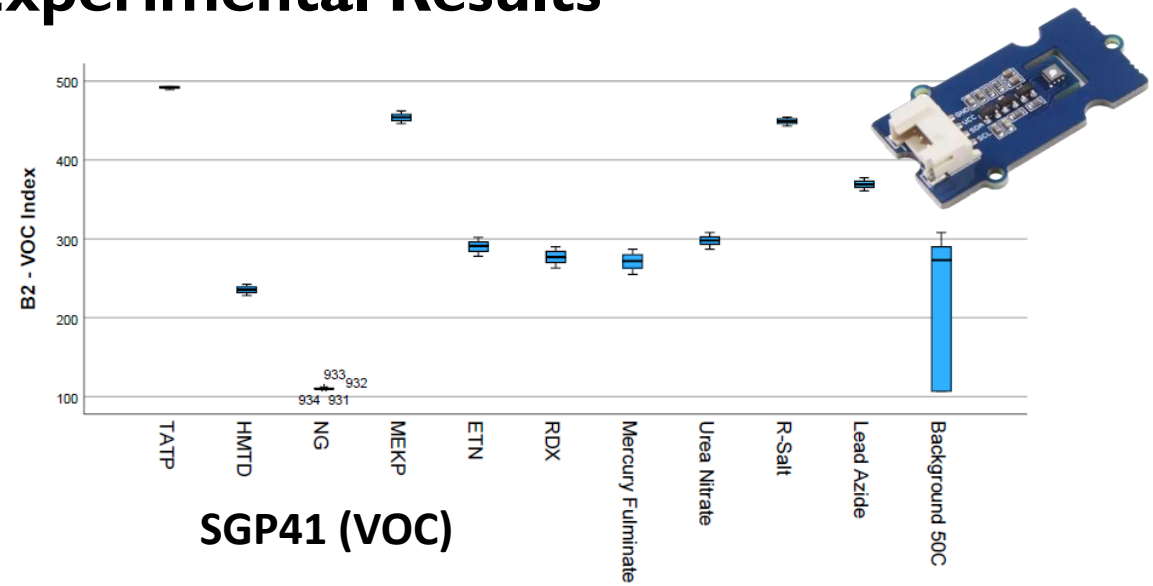
TGS2602 (e.g., NH_3, H_2S) and a broad range of VOCs

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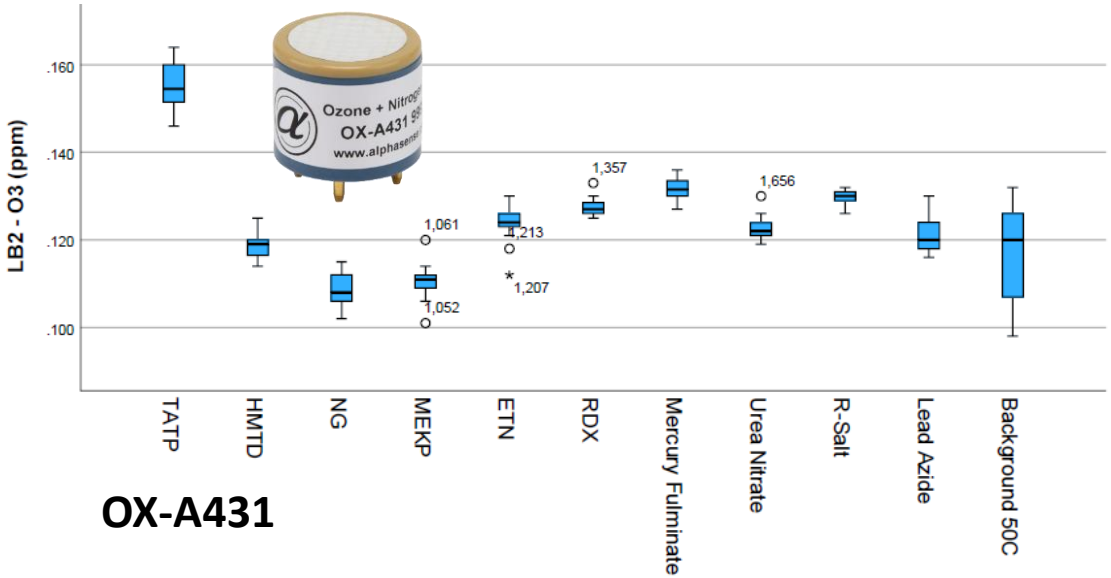
Univariate Analysis of E-Nose Experimental Results



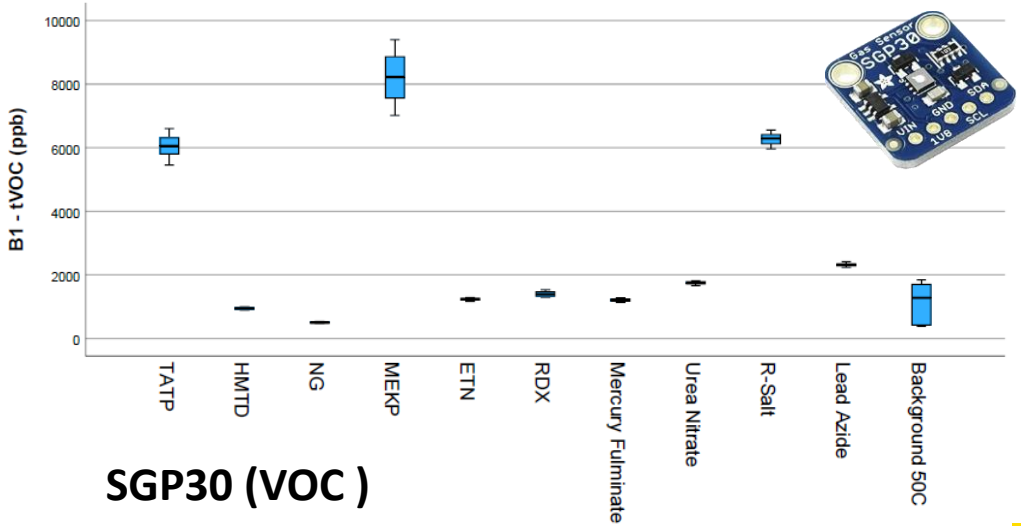
4-H2S-100



SGP41 (VOC)



OX-A431



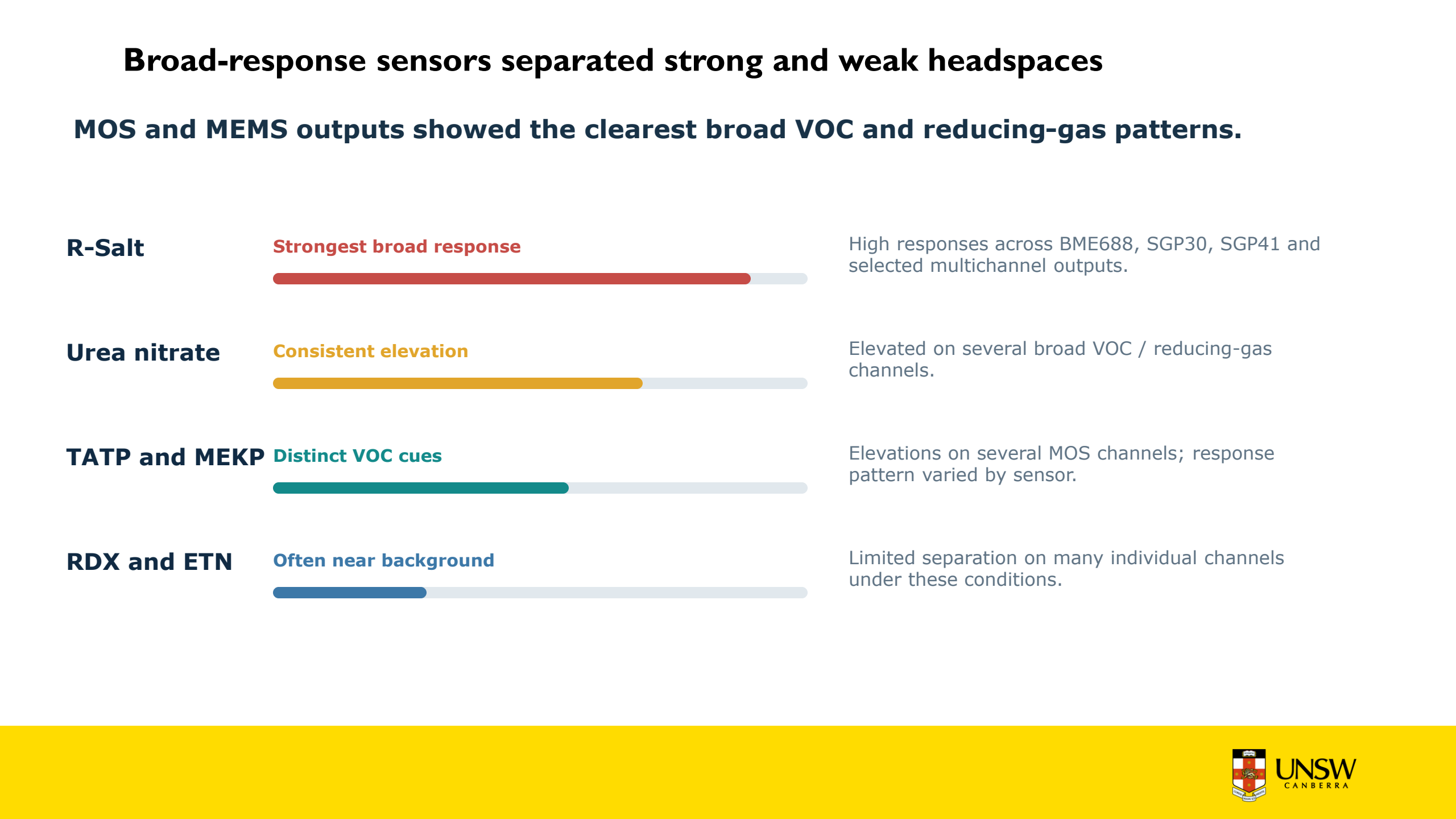
SGP30 (VOC)

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Broad-response sensors separated strong and weak headspaces

MOS and MEMS outputs showed the clearest broad VOC and reducing-gas patterns.

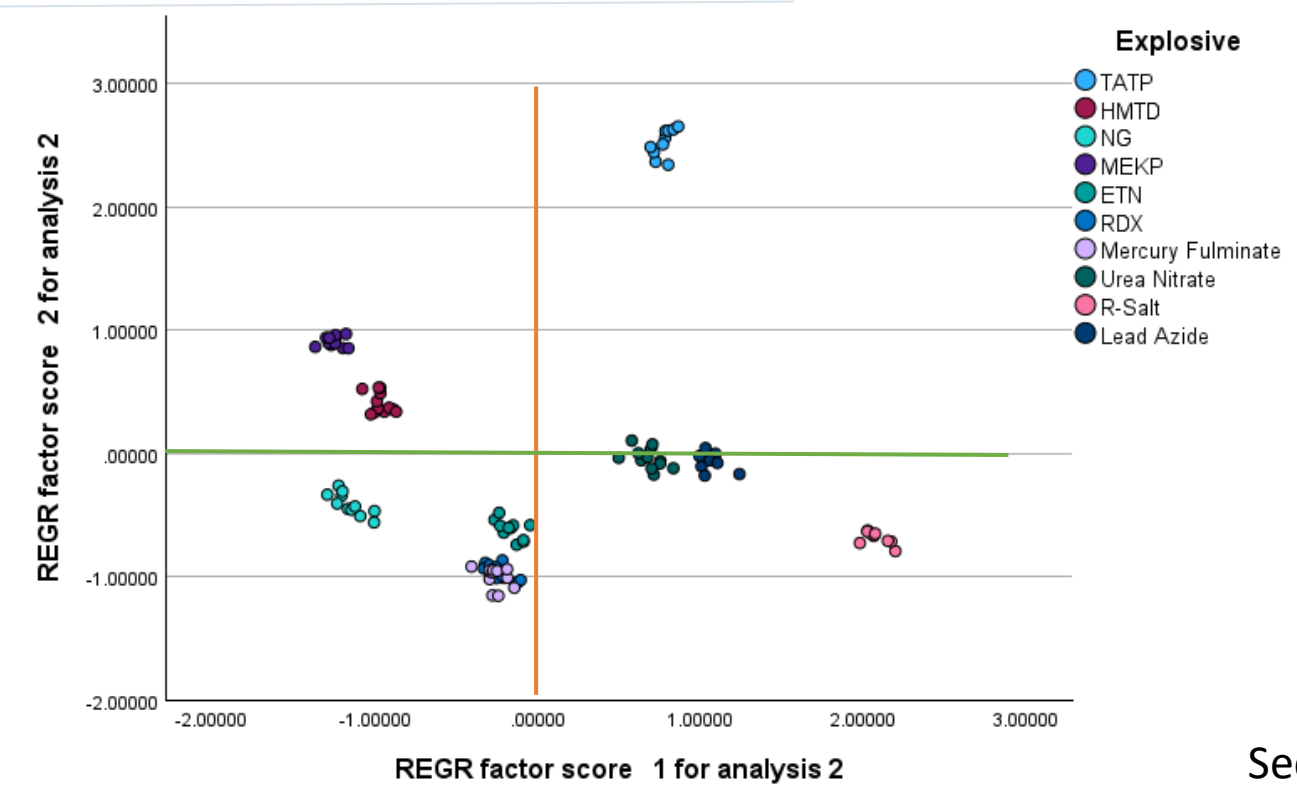
R-Salt	**Strongest broad response**	High responses across BME688, SGP30, SGP41 and selected multichannel outputs.
Urea nitrate	**Consistent elevation**	Elevated on several broad VOC / reducing-gas channels.
TATP and MEKP	**Distinct VOC cues**	Elevations on several MOS channels; response pattern varied by sensor.
RDX and ETN	**Often near background**	Limited separation on many individual channels under these conditions.



Multivariate Analysis of E-Nose Experimental Results

The PCA analysis proved that discrimination is governed by two orthogonal sensing mechanisms.

61.74% total variance captured



PC1 **40.43%**

PC1: broad MOS / VOC response

SGP30, BME688, SGP41 and other reducing-gas channels.

Metal-oxide semiconductor (MOS) sensors sensitive to overall VOC signatures and reducing gases controlled the dominant variance axis

PC2 **21.31%**

PC2: complementary selective channels

SFA30, NO-A4, OX-A431, H_2S and related channels.

Secondary axis was defined by chemically selective electrochemical sensors responsive to oxidising and nitrogen-containing species

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Conclusion

- Hybrid e-nose combining **MOS** (BME688, SGP30, SGP41, TGS2602, Multichannel v1/v2) and **electrochemical sensors** (SFA30—HCHO, NO-A4—NO, 4-H_2S-100—H_2S, OX-A431—O_3) can reliably differentiate explosive headspaces under controlled thermal conditions when interpreted as multi-channel patterns rather than single-analyte readouts.

- MOS channels with targeted electrochemical sensors enabled separation of chemically similar peroxide explosives such as TATP, MEKP, and HMTD

Thanks



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