

SEMI Standard MS14 Critical Parameters of Gas Sensors for Emerging Applications

Advanced Sensors
Webinar Series



Webinar
May 31, 2023
8:00-9:00 am PT



SEMI MS14-0422 Standard: CRITICAL PARAMETERS OF GAS SENSORS For Emerging Applications

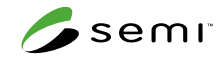
Sreeni Rao - GM, Gas and Environmental Sensing, Interlink Electronics

Radislav Potyrailo - Principal Scientist at GE Global Research

Ryotaro Sakauchi – Sr. Manager Business Development at Bosch Sensortec

May 31, 2023 (8am PDT)

Today's Webinar Presenters



Sreeni Rao

GM, Gas and
Environmental Sensing,
Interlink Electronics



Radislav Potyrailo

Principal Scientist
GE Research



Ryotaro Sakauchi

Sr. Manager
Business Development
Bosch Sensortec



Paul Carey

MSIG Director
SEMI

Webinar Agenda

- **Introduction to SEMI, MSIG, and SEMI industry standards activities**
- **Gas Sensor Standard Background and Rationale**
- **Gas Sensor Parameter Descriptions**
- **Obtaining the Standard**

SEMI

- **The** premier global semiconductor trade organization
- 2500+ member companies
- Your gateway to the semiconductor ecosystem



MEMS and Sensors Industry Group - MSIG

- 180+ member companies worldwide
- Value Proposition
 1. Education and **Networking** - *conference & events*
 2. Promotional opportunities - *SEMI blogs, webinars, social media*
 3. Collaborative problems solving - *industry task forces and workgroups*
 4. R&D funds - *\$25M 2022-2027 in positioning, navigation, and timing sensors*
 5. New opportunities and markets - *e.g. Biz Dev in Smart Cities*
- Get better business results faster!
- Visit msig.org

SEMI International Standards Overview



- **Established in 1973**
- **1,075+** published SEMI Standards & Safety Guidelines
- **5,000+** volunteer experts
 - 21 global Technical Committees
 - 200+ global Task Forces
- **2,000+** participating companies
- **Experts from semiconductor, PV, LED, MEMS & Display industries**
- **International presence**
 - United States | Japan | Europe | Taiwan | Korea | China

Exchange ideas and develop globally-accepted technical standards

SEMI MSIG MEMS Device Task Force

Item	Company	Representative	Comment
1	GE Research	Radislav Potyrailo	<i>US - Workgroup Chair <potyrailo@ge.com></i>
2	Bosch	Ryotaro Sakauchi	<i>US <ryotaro.sakauchi@us.bosch.com></i>
3	Interlink Electronics	Sreeni Rao	<i>US <srao@iesensors.com></i>
4	Camenzind Solutions	Mark Camenzind	<i>US</i>
5	Spec Sensors	Ed Stetter***	<i>US</i>
6	N5 Sensors	Debra Deininger	<i>US</i>
7	Renesas	Christian Meyer	<i>Germany</i>
8	Infineon	Tanja Hofner	<i>US</i>
9	Infineon	Mustahsin Adib***	<i>Germany</i>
10	Analog Devices	Ronan Colm	<i>US</i>
11	Arcelik	Merve Yunlu	<i>Turkey</i>
12	Siargo	Liji Huang	<i>US</i>
13	NREL	Michael Deru	<i>US</i>
14	Saarland Univeristy	Andreas Schutze	<i>Germany</i>
15	TEL	Angelique Raley	<i>US</i>
16	SEMI	Paul Carey	<i>US</i>

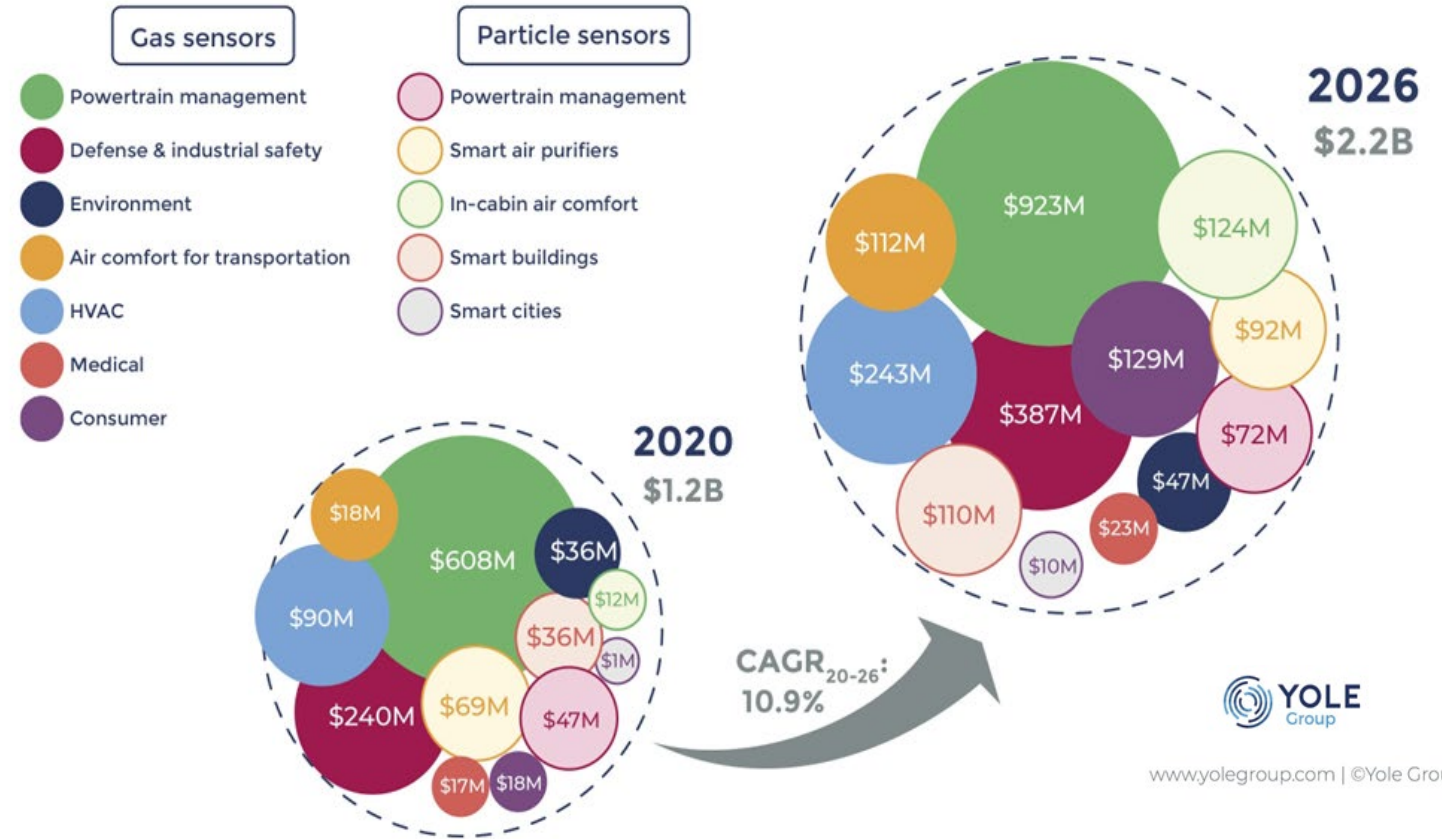
*** = former company (contact Paul Carey at pcarey@semi.org for more details)

Why a Gas Sensor Standard?

- Gas and particle sensors are a large and growing market
 - Gas sensor market alone is projected to be > \$1B by 2026
 - Applications for miniaturized gas sensors are emerging as well as the fastest growing

2020-2026 GAS AND PARTICLE SENSORS FORECAST - BREAKDOWN BY APPLICATION (\$M)

Source: Gas and Particle Sensors - Technology and Market Trends 2021 report, Yole Développement, 2021



Electrochemical and metal-oxide semiconducting sensing elements are the most popular

Trends, Requirements, and Opportunities for Sensors

Trends

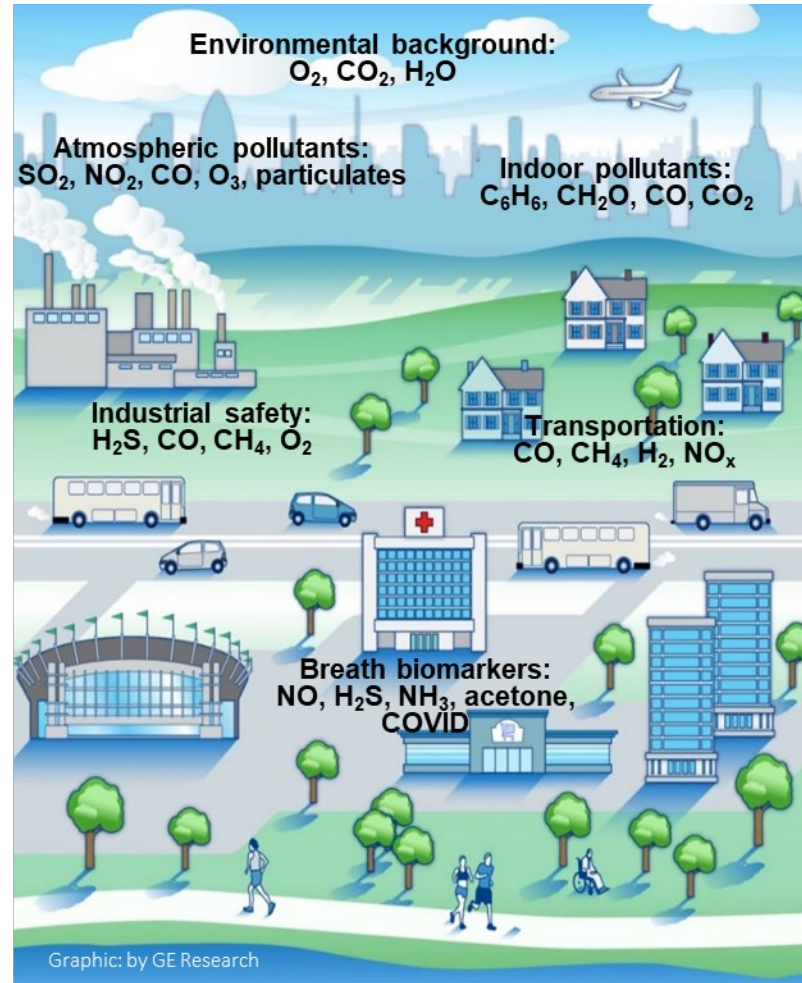
Industrial safety
Accuracy

Health / Fitness
Accuracy, Power

Environmental
Accuracy

Top 3 Sensor Needs

Accuracy
Cost
Power



Multi >\$1B Global markets driving gas sensors:

- Industrial safety
- Environmental monitoring
- Health self-monitoring
- Wearable sensors

... but they need to get better
(more accurate, lower power, lower cost)!

<https://www.marketsandmarkets.com/PressReleases/safety-instrumented-system.asp>
<https://www.sensormag.com/components/food-safety-testing-market-worth-16-1-billion-usd-by-2020>
<https://www.prnewswire.com/news-releases/health-self-monitoring-technologies-and-global-markets-300102733.html>
<https://www.mordorintelligence.com/industry-reports/global-wearable-sensors-market>
<https://www.grandviewresearch.com/industry-analysis/gas-detection-equipment-market>
<https://www.globenewswire.com/en/news-release/2023/01/26/2595862/0/en/Environmental-Monitoring-Market-Size-worth-17-9-billion-by-2026-Exclusive-Report-by-MarketsandMarkets.html>

R. Potyralo, *IEEE SENSORS 2022*

Why a Gas Sensor Standard?

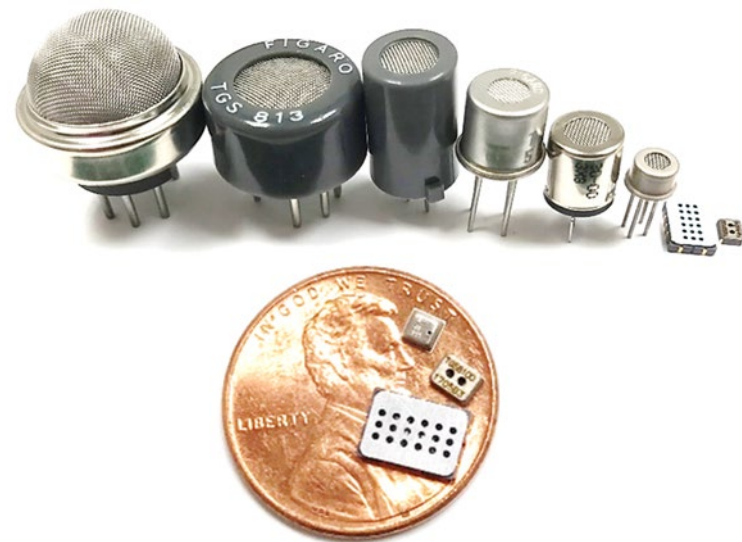
- To support this growing demand, a common understanding of gas sensors is needed:
 - Ensures consistent product quality
 - Ensures easy comparability
 - Promotes consumer confidence
- The MS14-0422 Gas Sensor Standard from the MSIG Device Working Group provides:
 - Standard parameter recommendations and their definitions
 - Test and measurement methodologies
- Further details on these topics can be found in our blog from June 2022:
<https://www.semi.org/en/blogs/semi-news/exploring-market-demand-for-pervasive-gas-monitoring>



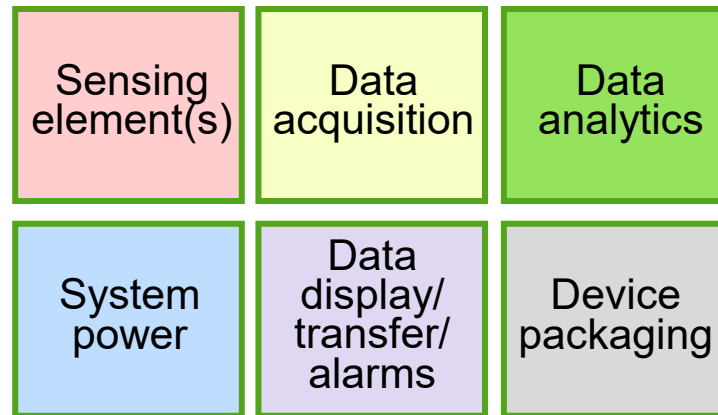
SEMI Device Workgroup Gas Sensor Blog

Scope of the MS14-0042 Standard

- A **sensing element** is a part of a **sensor system**
- The current standard focuses on the sensing element rather than the final device
- Recommends which parameters should be included in a datasheet for a gas **sensing element**



*Illustrative examples of **sensing elements***

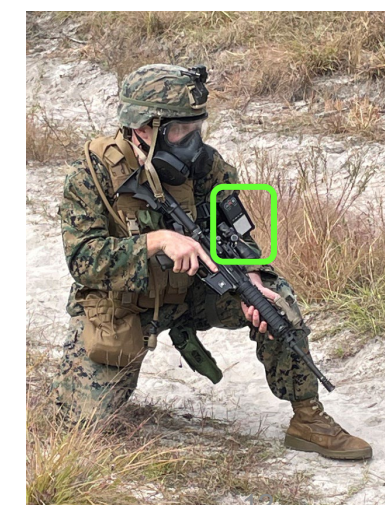
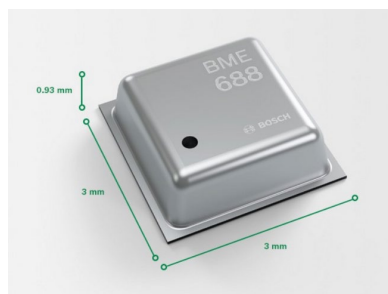
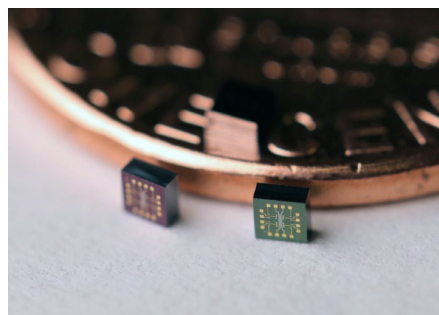


*Illustrative example of schematic of **sensor system***



*Illustrative examples of **sensor systems***

Primary Application	Standards, Guidelines and Reports
Indoor Air Quality	UL Environmental Standard 2905 Environmental Claim Validation Procedure for Indoor Air Quality (IAQ) Sensor Performance
Indoor Air Quality	LBNL Performance assessment of low-cost environmental monitors and single sensors under variable indoor air quality and thermal conditions
Air Quality	WHO global air quality guidelines: Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide.
Air Quality	RESET® 空气 RESET® Air, an international data standard for air quality monitoring
Safety	UL 2075 Standard for Gas and Vapor Detectors and Sensors
Homeland Security	ASTM E2885 – 13 Standard Specification for Handheld Point Chemical Vapor Detectors (HPCVD) for Homeland Security Applications
Department of Defense	MIL-STD-810H Department of Defense Test Method Standard



Illustrative Gas Sensor Parameters

- Dynamic Range
- Accuracy
- Cross-sensitivity
- Drift over time
- Environmentally induced drift (T, RH, P)
- Warm-up time
- Response and Recovery time
- Repeatability

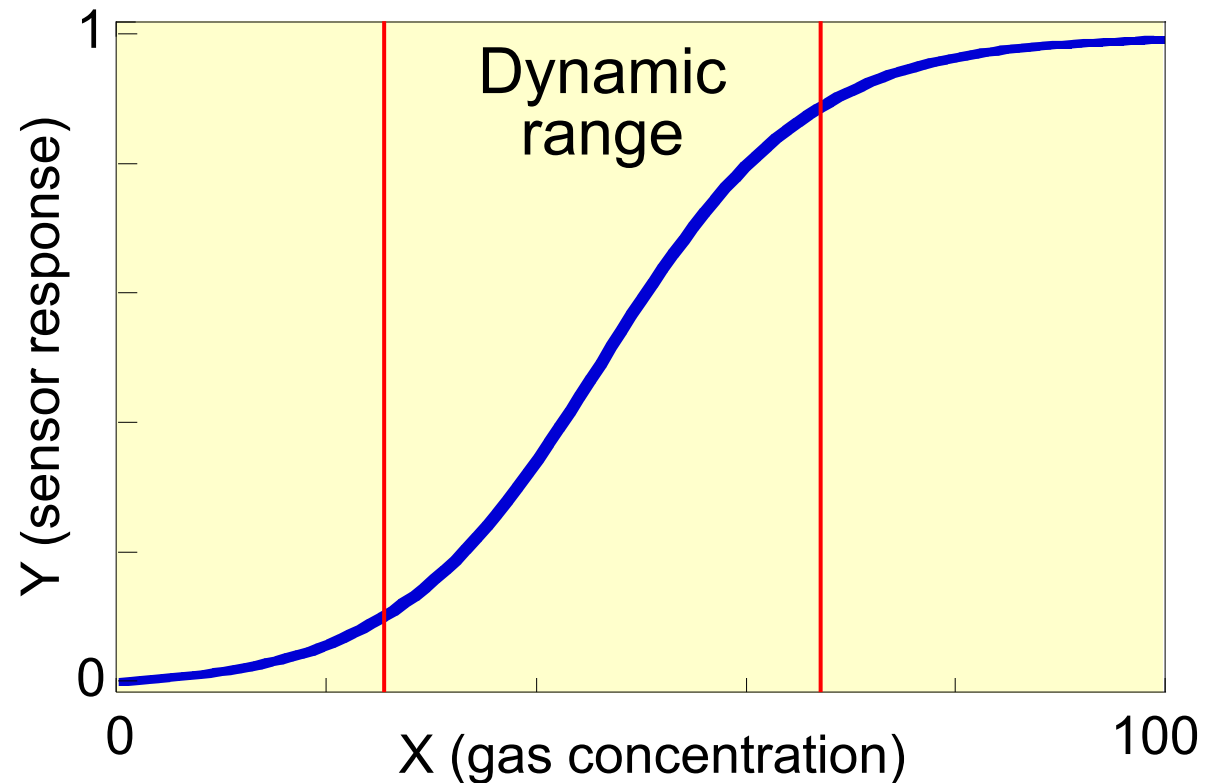
As appropriate, gas sensor parameters are measured using high-quality benchmark equipment

Dynamic Range

The lower and upper limits of gas concentration detected reliably by the sensor

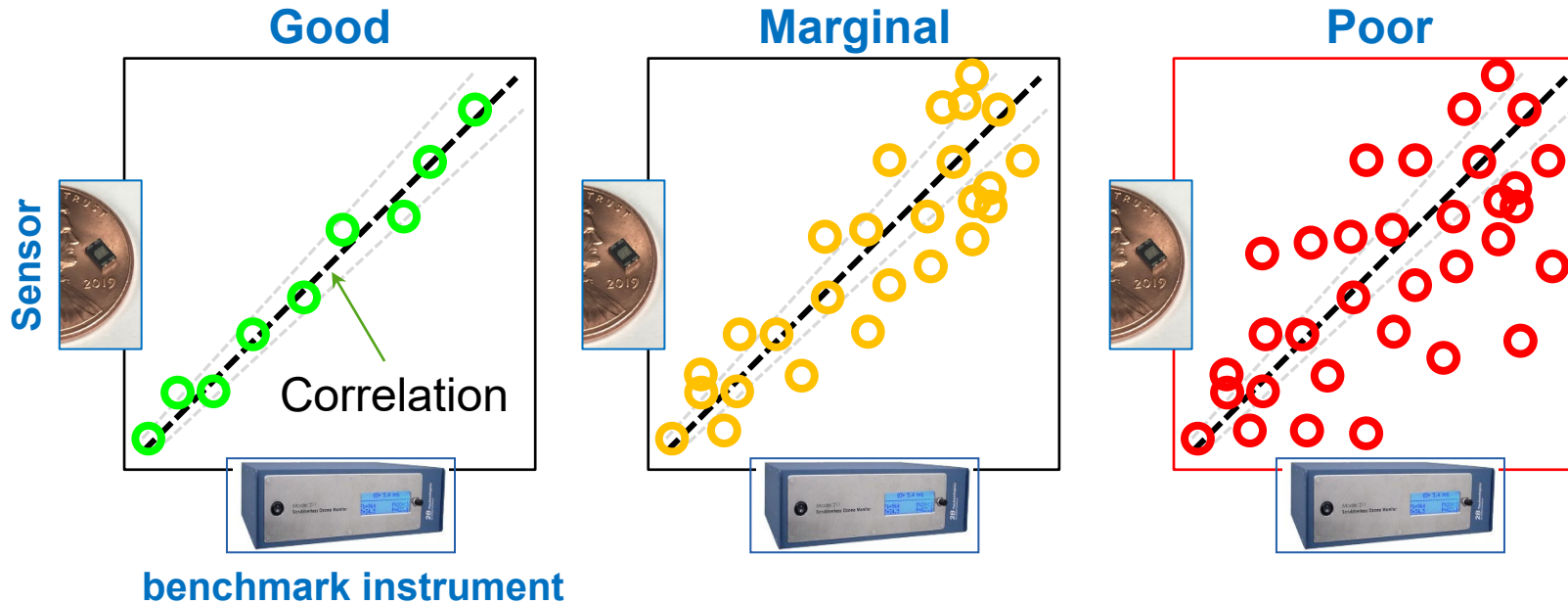
Typical ranges of common gases

Gas	Application	Typical Range
Carbon Dioxide, CO ₂	Indoor Air Quality	400 – 5000 ppm
Carbon Dioxide, CO ₂	Leaks, Breath, etc.	0.5 – 20%
Carbon Monoxide, CO	Indoor Safety	0 – 500 ppm
Nitrogen Dioxide, NO ₂	Outdoor Air Quality	0 – 2 ppm
Nitrogen Dioxide, NO ₂	Industrial Safety	0 – 20 ppm
Ozone, O ₃	Air Quality	0 – 600 ppb
Oxygen, O ₂	Safety	0 – 30%
Formaldehyde, HCHO	Indoor AQ, Health	400 – 1000 ppb
Hydrogen, H ₂	Safety	0 – 1%
Methane, CH ₄	Safety	0 – 1%
VOC (non-specific)	Indoor Air Quality	0 – 30 ppm



Accuracy

Departure of gas concentration values measured by **the sensor** from values measured by a **benchmark instrument**



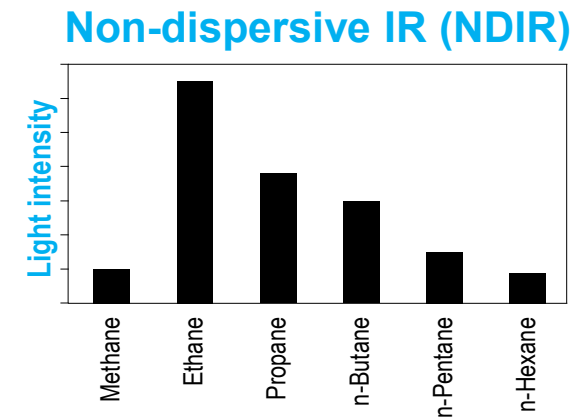
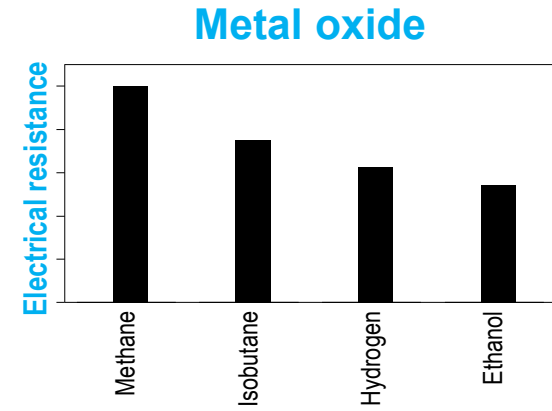
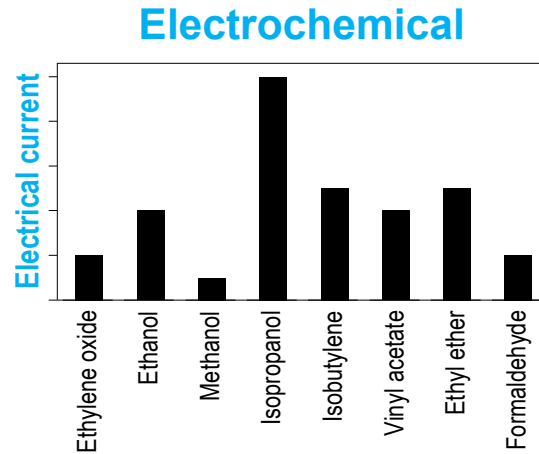
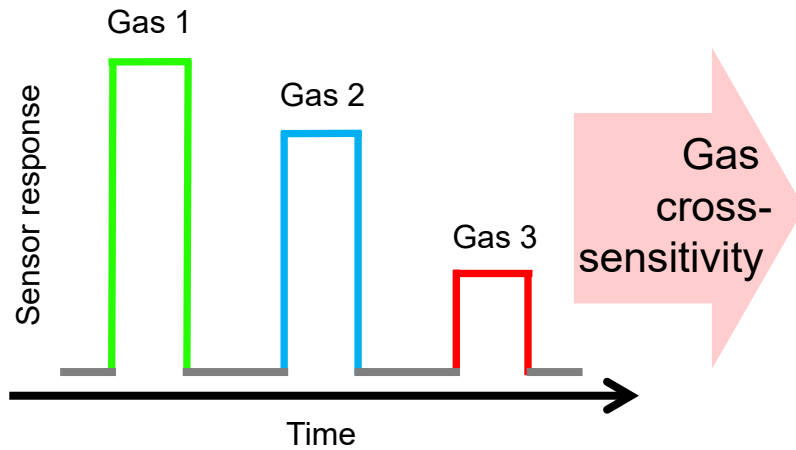
Diverse applications have different levels of acceptable accuracy:
 e.g. general air quality, industrial safety, medical diagnostics –

- From consumer to mandatory and regulatory purposes
- From informational to control actions

EPA
 Data of poor or unknown quality is less useful than no data since it can lead to wrong decisions
 - *Environmental Science and Technology*, 2013, 47, 11369–11377

Cross-Sensitivity

Gas cross-sensitivity is sensor response to gases other than the gas of interest



nature
The biggest headaches are caused by interfering chemicals
Nature, 2016, 535, 29-31

EHS Today
Understanding cross sensitivities can certainly help to keep workers safe
-EHS Today, 2018

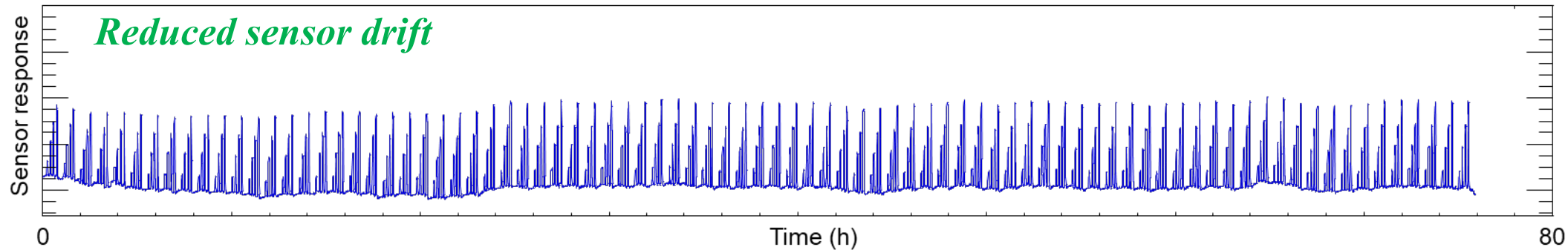
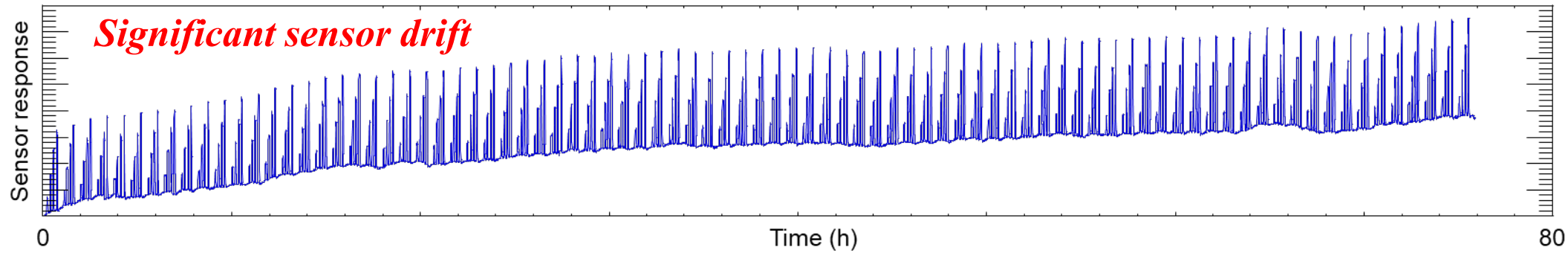
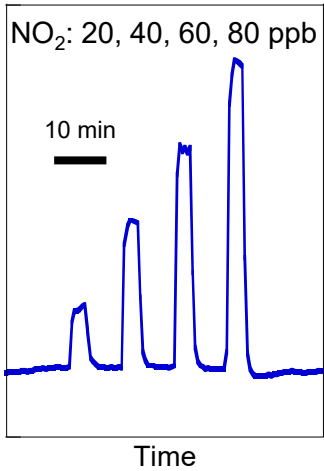
All offered (electrochemical, metal-oxide semiconducting, NDIR, etc) sensing elements are single-output devices

Sensor Drift

Slow change in sensor response such as baseline drift, sensitivity drift or both

87 replicate cycles

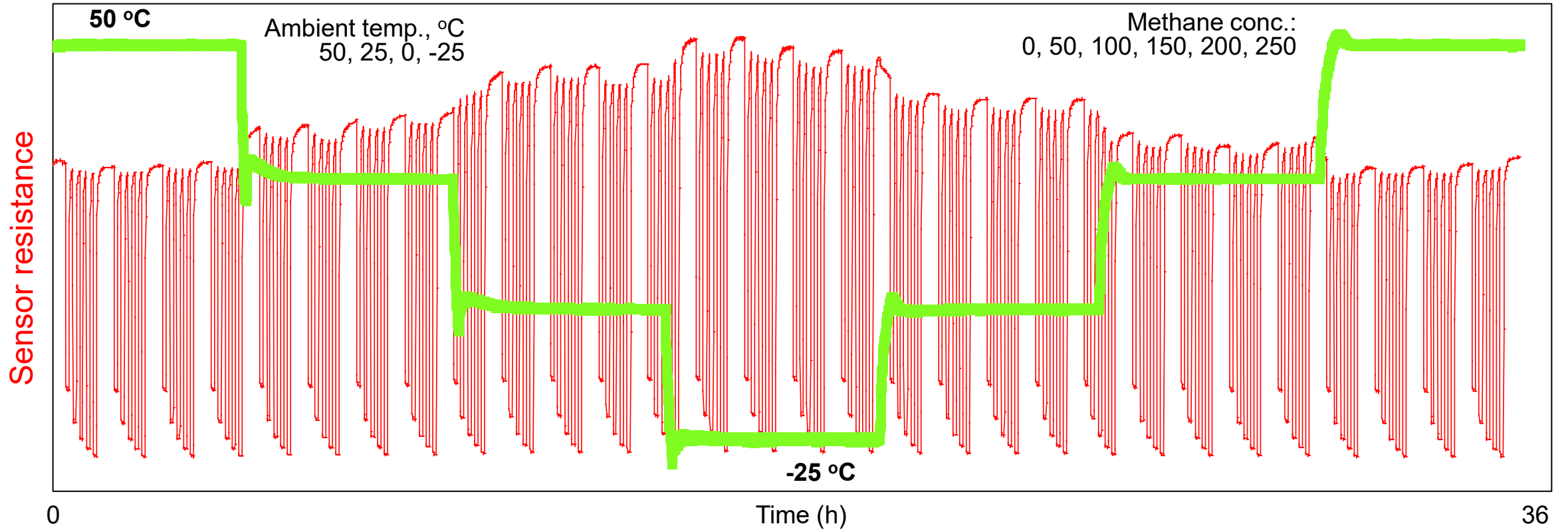
One cycle



As appropriate, gas sensor parameters are measured using high-quality reference equipment

Environmentally induced drift (Temperature)

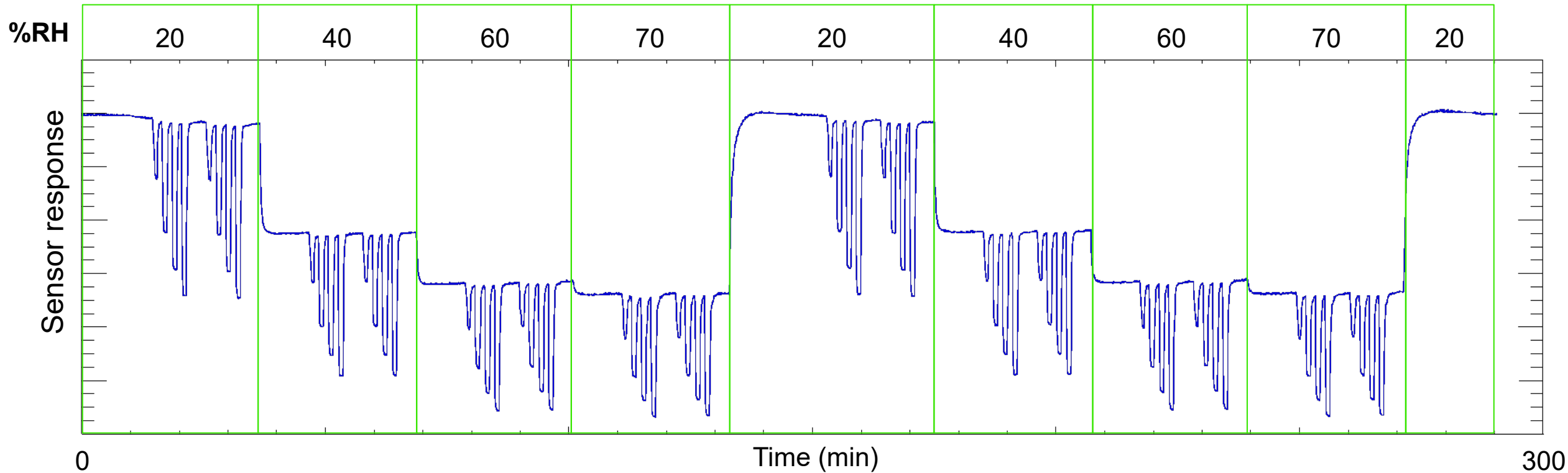
Temperature-effected change in sensor response



Environmentally induced drift (Humidity)

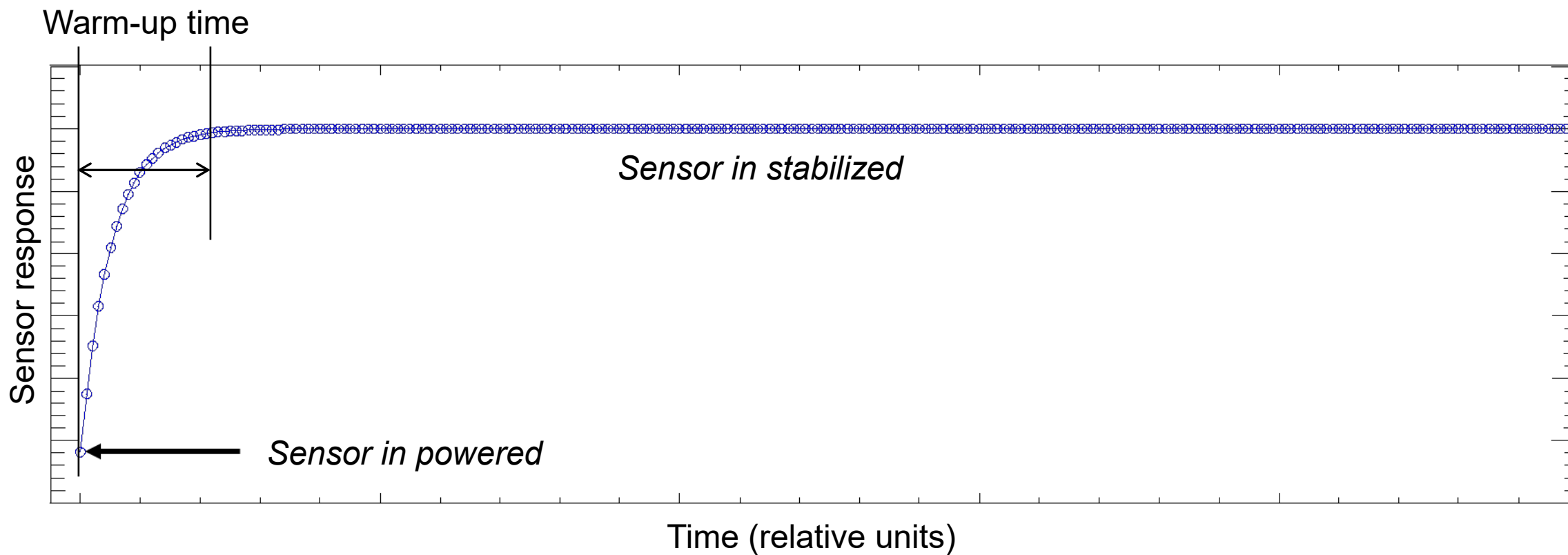
Change in a sensor's reported gas concentration value per unit change in humidity

Hydrogen conc.: 250, 500, 750, 1000



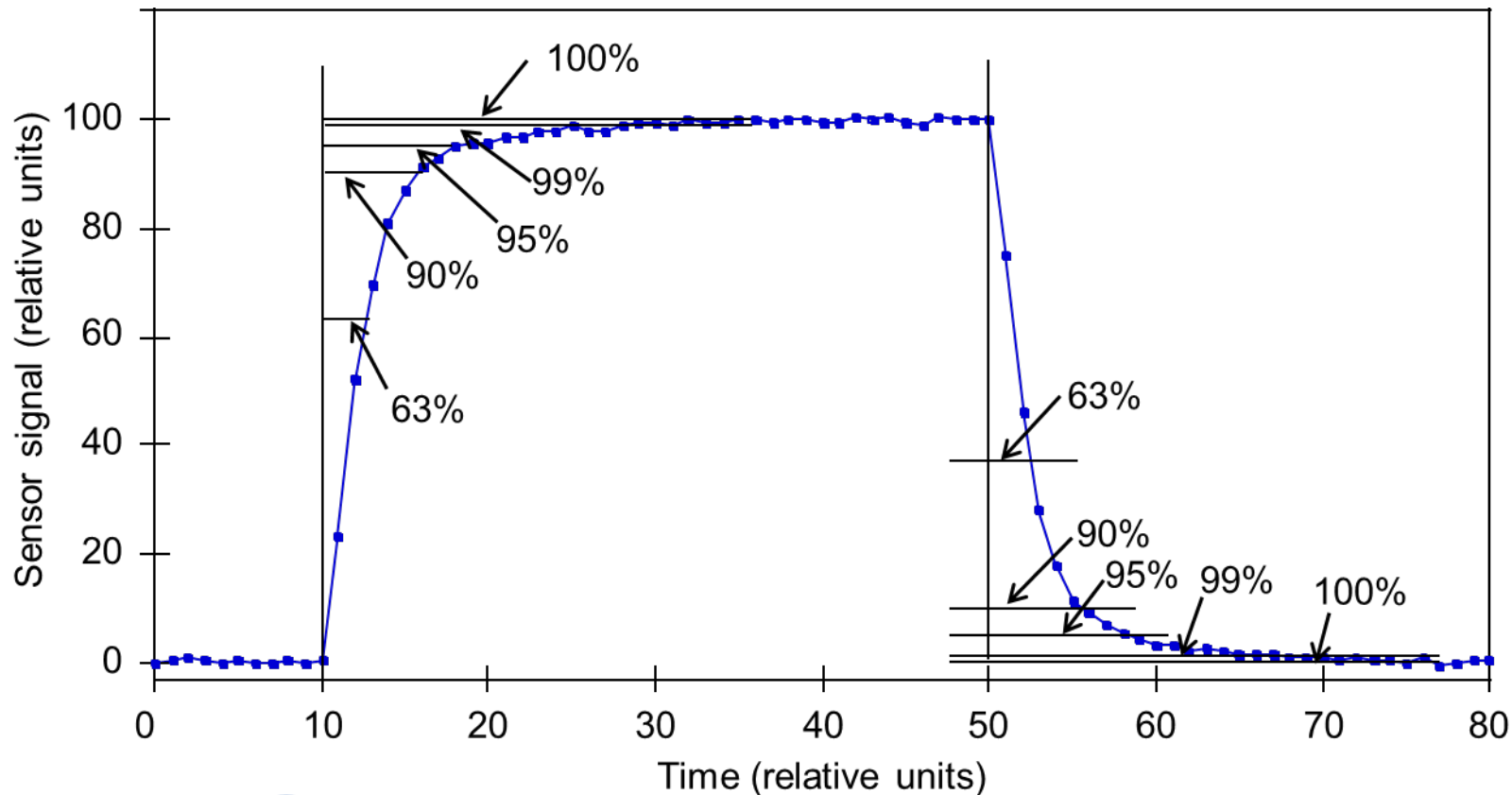
Warm-up Time

Time from the sensor is powered to when the sensor has reached the accepted performance



Response and Recovery Time

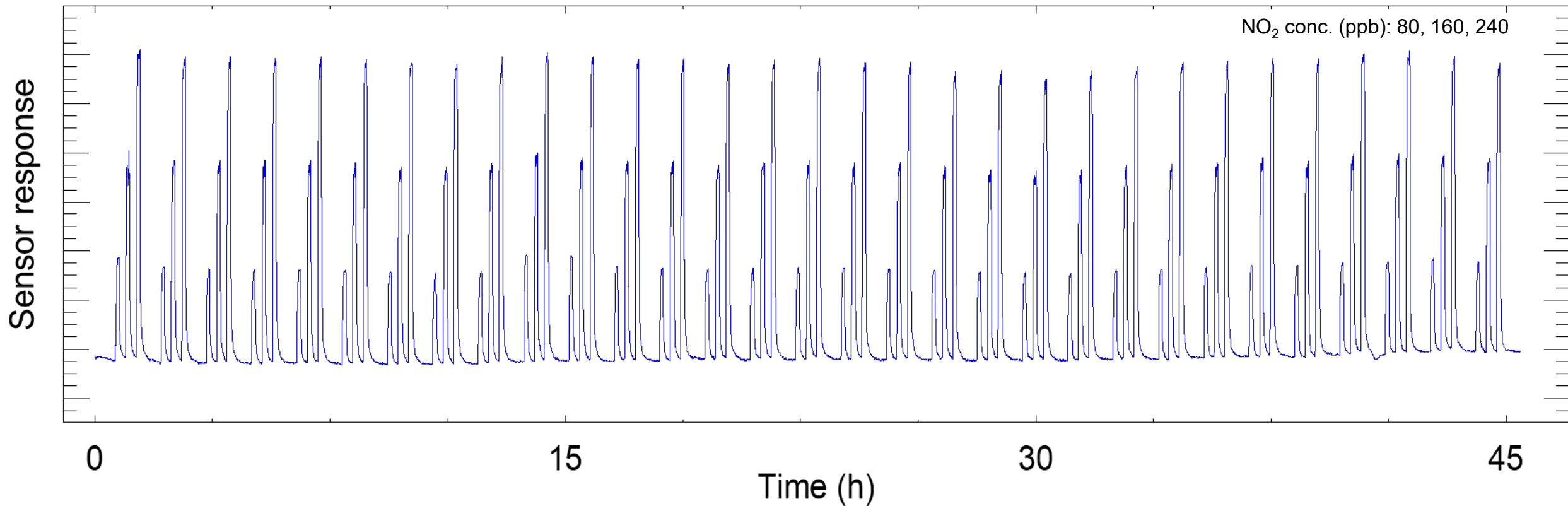
Elapsed time between two events (a) when an (instantaneous) change happens from clean air to standard test gas to be sensed; and (b) when the sensor response reaches a standard percentage (x) of the stabilized response.



- The percentage used for the response time of most gases is $t(90)$, time to 90% of the stabilized signal
- In cases where gases are particularly reactive or challenging to handle, using the $t(50)$ or 50% of the final value is more appropriate
- **Recovery time** is essentially the converse of this notion – i.e., when the stimulus gas concentration drops down to zero

Repeatability

A measure of how often the sensor correctly reports the target concentration when exposed to the same concentration of the standard test gas multiple times.



Obtaining SEMI MS14 - Guide for Critical Parameters of Gas Sensors

- Online: <https://store-us.semi.org/products/ms01400-semi-ms14-guide-for-critical-parameters-of-gas-sensors>
 - SEMI Member Company Price: **\$130.00**
 - Non-Member Company Price: **\$170.00**
 - Volume(s): MEMS
 - Language: English
 - Type: Single Standards Download (.pdf)

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standard here



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For Further Information

- SEMI MSIG: contact [Paul Carey](#)
- SEMI Standards: contact [Laura Nguyen](#)
- Gas Sensor Technology
 - [Sreeni Rao](#) – GM, Gas and Environmental Sensing, Interlink Electronics
 - [Ryotaro Sakauchi](#) – Sr. Manager Business Development at Bosch Sensortec
 - [Radislav Potyrailo](#) – Principal Scientist at GE Global Research



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Atomic Layer Deposition (ALD) Solutions for MEMS and Actuators

**MEMS Manufacturing
Webinar Series**



Dilip Deshpande
Director, BusDev & Sales
North America
Beneq



Webinar
June 8, 2023
8:00-9:00 am PT





THANK YOU For Joining!

