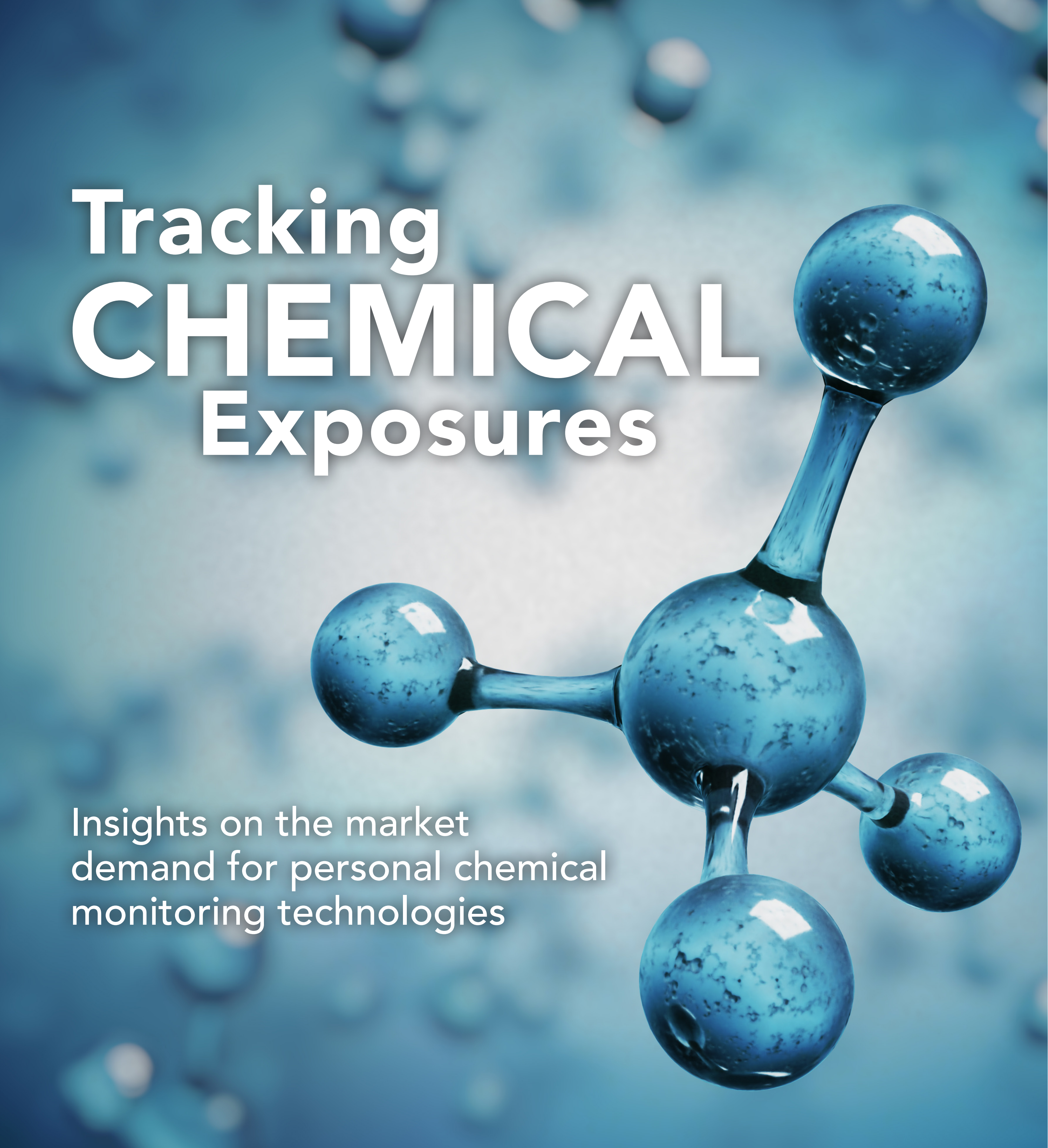
Tracking CHEMICAL Exposures



Insights on the market demand for personal chemical monitoring technologies

JULY 2019

EDF ENVIRONMENTAL DEFENSE FUND® Finding the ways that work

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Tracking Chemical Exposures

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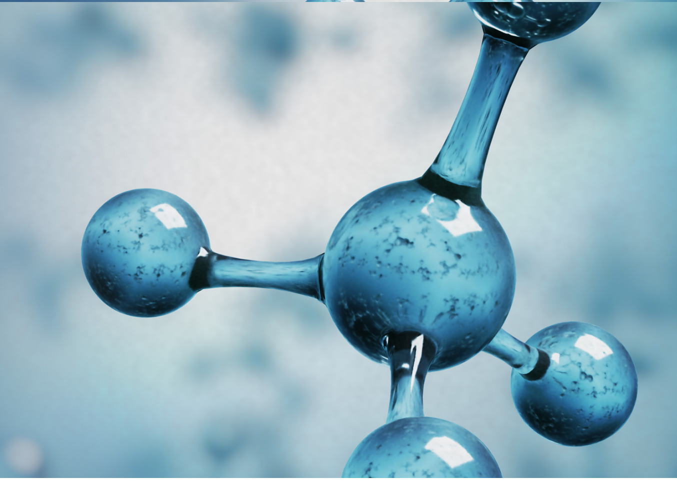


ABOUT

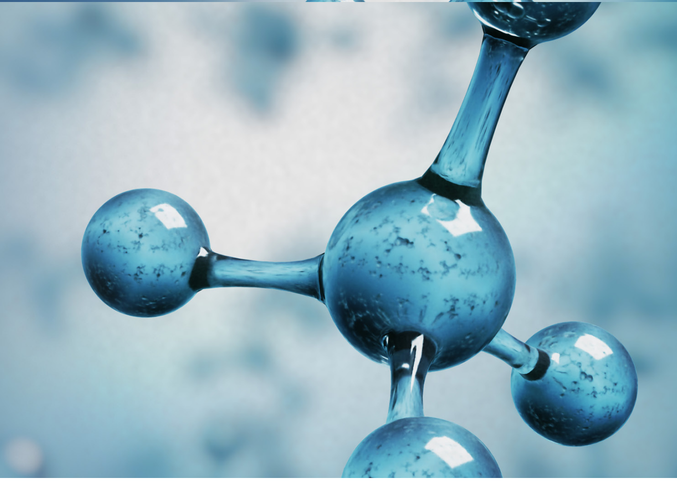
ENVIRONMENTAL DEFENSE FUND

The goal of the health program at Environmental Defense Fund (EDF) is to improve human health through reductions in exposure to harmful chemicals and pollution. EDF's health program uses the dual levers of public policy and corporate leadership to phase harmful substances and practices out of the market and introduce safer products and practices into mainstream use. We encourage and support innovations that work toward this end.

THIS REPORT

EDF envisions a world where robust information on all types of chemical exposures enables evidence-based decisions that result in measurable reductions in harmful exposures. In 2017, EDF pursued a Year of Innovation to better understand the potential of personal chemical exposure monitoring and to activate a network interested in driving the development, uptake, and scaling of breakthrough technologies. As part of this effort, EDF conducted interviews and convened a workshop involving engineers, entrepreneurs, and public health and policy experts to explore opportunities to enable the development and use of lower-cost, portable or wearable personal chemical exposure monitors.

One of the main takeaways from the expert workshop is that a significant gap exists between the demand and promise of such technologies and the current cost or scalability of many of the available technologies. Experts noted that while there is significant qualitative or anecdotal evidence of demand for such technologies, a quantitative understanding of the potential market for these technologies is needed to drive a robust market. This report addresses this gap by quantifying the demand for personal chemical monitoring technologies.



EXECUTIVE SUMMARY

New technologies offer opportunities to fill critical information gaps in environmental health. Personal monitoring technologies, in particular, hold promise to dramatically increase information about everyday exposures to harmful chemicals. This analysis is a first-of-its-kind landscape assessment of the market demand for technologies capable of detecting an individual's exposure to harmful chemicals.

Chemicals make up the material backbone of products in commerce—from couches and carpets to clothes and cleaning products. While chemicals serve an important role in our economy, they also end up in our environment—in our water, land, and air—and our bodies. Some of these chemicals are hazardous and exposure to them—whether through environmental releases, workplace exposures, or use of products—can lead to health problems such as asthma, learning disabilities, and cancer. Unfortunately, we have insufficient information about exactly which chemicals individuals are exposed to and in what amounts. Without this information it is challenging for individuals to determine how best to reduce their exposure to harmful chemicals, or for government agencies, companies, health professionals, and others to develop effective policies and interventions to protect public health from harmful chemicals.

A new category of technologies entering the market may change the status quo: personal chemical exposure monitors (PCEMs). These technologies are a new entrant in the rapidly growing "monitored-self" market, joining a suite of available products designed to help people monitor and understand their individual health—from home-delivered kits that screen for genetic conditions to heart rate-monitoring watches.

PCEMs are a diverse set of technologies. They use different chemical detection methods, come in different forms, and exhibit different functionality. Some may be packaged as a kit, requiring the user to submit a biological sample like urine or saliva. Others may be worn on the body, absorbing chemicals that the wearer encounters during everyday activities. There may be other differences too, including the number of chemicals detected, how long it takes to get the results, or how many scans the device can provide.

ASSESSING THE DEMAND FOR PCEMS

To accelerate and inform the efforts of PCEM technology developers, investors and other stakeholders, EDF conducted a two-part study to assess market interest in personal chemical exposure monitoring technologies. EDF commissioned a survey to characterize consumer willingness to pay for various hypothetical PCEM technologies, enabling exploration of what features are most valued. To provide additional perspective, EDF also interviewed 16 experts from across the supply chain—ranging from investors and technology developers to industrial hygienists and potential institutional customers—on success factors and challenges confronting this emerging market. While the primary focus was on opportunities in the general consumer market, interviewees included eight individuals with expertise on monitoring chemicals in the workplace.

KEY FINDINGS

Our consumer willingness to pay survey found a clear market for PCEMs among general consumers:

- Consumers were willing to pay $459 for a device that includes all surveyed premium features.
- Nearly 40 hypothetical devices had a willingness to pay in the $100 to $300 range—a price range

reflective of the actual price of other personal monitoring devices on the market today.

- 70 hypothetical devices had a positive willingness to pay, generally relying on the presence of at least two surveyed premium features.
- The features that consumers valued the most were receiving 1) data on a large number of chemicals, 2) immediate results, and 3) information on both level of exposure and whether such exposure is of concern.

The consumer survey identified certain segments of the market more willing to:

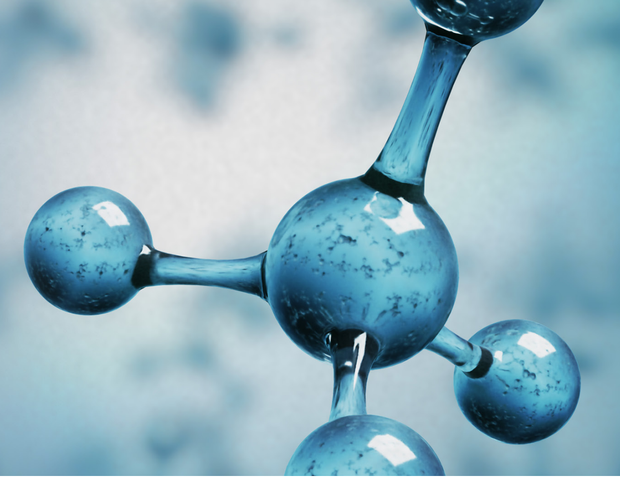
- Purchase a device, including those who are younger, those who are college-educated, and those who self-reported having healthier habits.
- Pay more for devices with premium features, including women and those who self-reported as exposed to chemicals at work.

In interviews, experts from companies like Google, 23andMe, and Safer Made (a venture capital firm), as well as technical experts from government and medicine, point to the demand for PCEMs from consumers and from those in the occupational monitoring sphere. They also identified market opportunities for these technologies and suggested ways to overcome existing and anticipated challenges. Key insights and themes that arose through the expert interviews:

- Consumer demand for PCEMs is poised to increase as awareness of the health impacts from harmful chemical exposures continues to grow.
- PCEMs could fill gaps in traditional workplace chemical monitoring, ultimately leading to better characterized and healthier worker environments.
- Device features that would be especially valued in the occupational health sphere include user comfort, real-time exposure notifications, and the ability to provide results quickly.
- Opportunities to break through bottlenecks to broader market uptake include driving down cost, emphasizing consumer education, understanding potential responsibility concerns, and identifying and targeting "early adopters" to build the market.

OPPORTUNITY IN A GROWING MARKET

Our research shows that demand for PCEMs exists today, and we anticipate the demand to increase over time given the expanding market for health and wellness technologies and rising concerns about chemicals in the environment. Consumers are already purchasing devices to monitor their health and wellness, and it is easy to envision the more nascent PCEM market developing into an established technology within this broader context. Entrepreneurs who can bring viable personal chemical monitoring products into commerce have an incredible opportunity to claim part of a large and rapidly growing health and wellness market.



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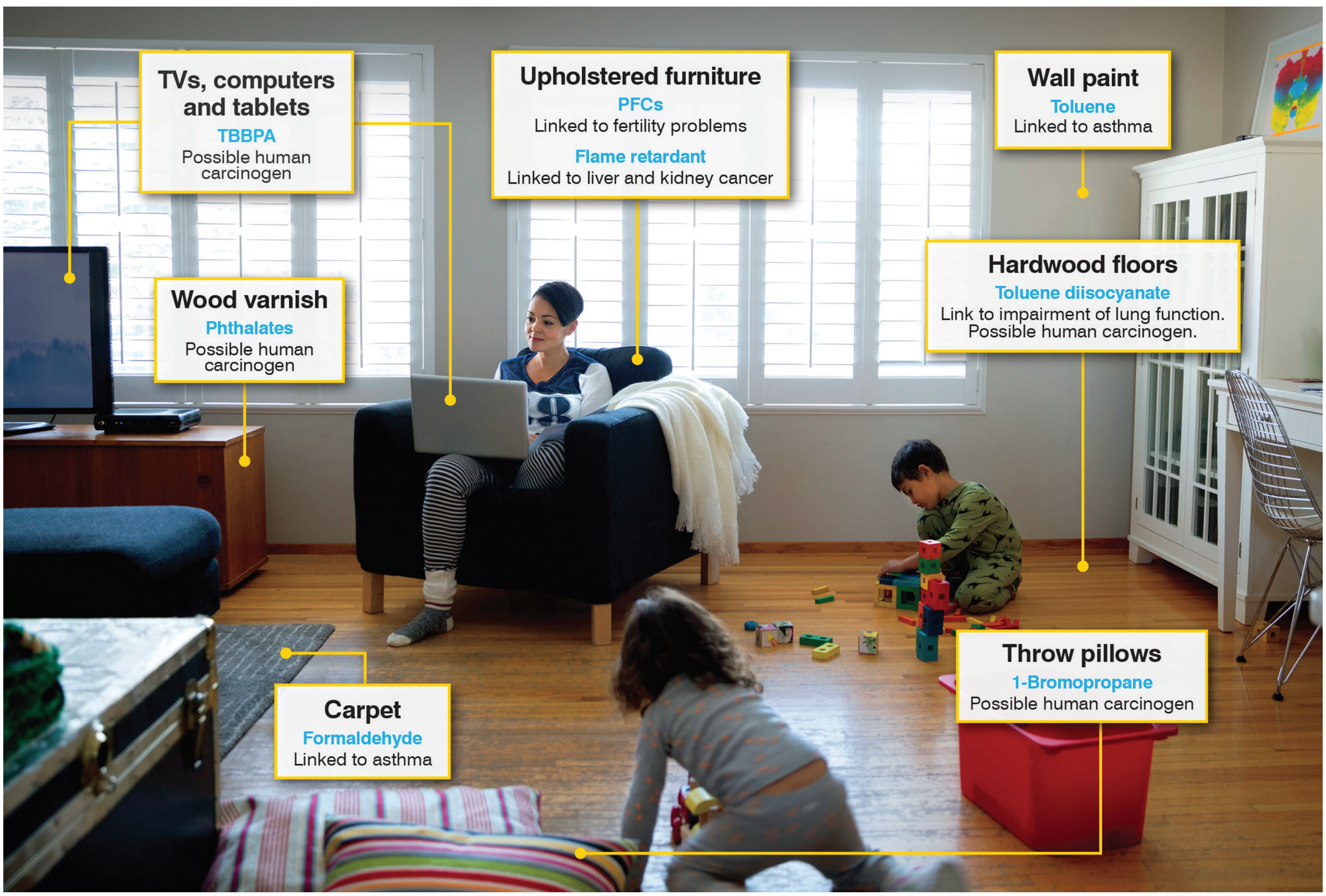
1 | INTRODUCTION

Chemicals make up the material backbone of products in commerce—from couches and carpets to clothes and cleaning products. Common types of chemicals found in consumer products include chemical fragrances, plasticizers, flame retardants, and pesticides, all of which have been widely detected in the bodies of Americans.[1] Some chemicals are hazardous and can find their way into our environment, whether emitted by industrial processes or released by products themselves, ultimately ending up in our water, land, and air—and in our bodies. Exposure to certain chemical substances have been linked to a variety of adverse health impacts including reproductive harm, disruption of normal hormone activity, and impaired neurological



Thousands of household goods—cleaning and personal care products, furniture, electronics, and wall and floor coverings—have been found to contain chemicals linked to a number of serious health concerns.

development in children.[2] Infants and children are particularly susceptible to harmful chemicals because of their unique behaviors (e.g., crawling on the floor, putting their hands in their mouths) and their physiology (e.g., developing organs, higher breathing rates).[3]

Unfortunately, we have insufficient data about which chemicals individuals are exposed to and at what levels. Without this information, government agencies, companies, health professionals, and others cannot effectively assess health risks or identify policies and practices for reducing exposures to hazardous chemicals, and individuals struggle to determine how they can best reduce their exposures to harmful substances.

There is a growing awareness and concern about exposure to harmful chemicals. Some individuals have health conditions that are exacerbated by certain chemical exposures. Others may be worried about exposure from nearby industrial sources or nearby contaminated waste sites. Still others may be unsure about what they could be exposed to while at work or even in their own homes. Those who are considering becoming pregnant or are already pregnant may want to better understand their chemical exposures while trying to conceive or during critical fetal development periods to assess if there are opportunities to reduce exposure to certain hazardous chemicals.

So what if there was a simple way for anyone to monitor their personal chemical exposures? What if anyone could use a simple home-delivered kit or wearable device to reveal the chemicals in their environment—or body? Such technologies can make the invisible visible—providing individuals as well as policy makers, businesses, health professionals, and others with critical information needed to accelerate reductions in the public's exposure to hazardous chemicals.

THE MONITORED-SELF REVOLUTION

Using wearable devices to monitor and track personal health indicators is a growing trend in health and wellness. In a 2017 study, market research firm BCC Research valued the global market for health self-monitoring technologies at $20.7 billion and projected this market to grow at a more than 25% compound annual growth rate—reaching $71.9 billion by 2022 (see Figure 1).[4] Devices and tools are now available that can:

- Sample the breath of diabetes patients to help monitor blood sugar levels;
- Alert wearers when they are being exposed to high UV radiation;
- Externally monitor an infant's blood oxygen level and heartbeat;
- Provide medical-grade electrocardiogram results through fingertip sensors;
- Continuously monitor heart rate, respiratory rate, activity levels, position and posture;
- Track calorie consumption; and
- Monitor sleep patterns and sleep quality.

A number of these existing devices are priced in the $100 to $500 range.[5,6,7,8] Future developments will expand the range of characteristics that can be self-monitored and enhance the usefulness of the data that are collected. Pioneers in this emerging technology space see a future where devices provide actionable feedback that can help users improve health and wellness outcomes.

FIGURE 1 | Projected Market Growth for Health Self-Monitoring Technologies

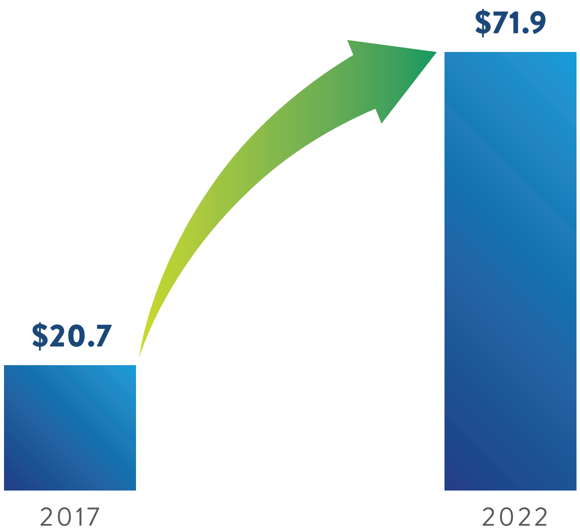


Figure based on BCC Research, 2017

The monitored-self revolution isn't limited to wearable gadgets. People are also looking inward—paying a premium to learn about their genetics. Genetic screening has transformed over the past decade: In 2006 a human genome cost $14 million to sequence. In 2016, only a decade later, it cost under $1,500. That's almost *10,000 times* cheaper.[9] And today, individuals can learn about their genetic makeup and ancestry by simply sending a saliva sample for analysis for about $100–$200.

PERSONAL CHEMICAL EXPOSURE MONITORS

Personal chemical exposure monitors (PCEMs) can provide information about an individual's chemical exposures using a variety of different technologies. Biomonitoring services provide information about chemicals actually absorbed into the body, while wearable devices measure chemicals that are present in the external environment surrounding the individual.

Biomonitoring services typically come in a kit, requiring the user to collect a biological sample (e.g., urine). These kits include a sample storage container, which the user then returns for laboratory analysis. Other chemical detection technologies come in the form of wearable devices that absorb chemicals while being worn by the user. The user then sends the device for analysis by a laboratory. There are also wearable devices available or under development that report exposure information immediately or shortly after download to a computer or smartphone.

In addition to coming in different forms, PCEMs also differ with respect to the type and number of chemicals they can detect, the speed with which results can be delivered, and the number of analyses included (e.g., one time only, unlimited scans). Technology developers may or may not include additional interpretation of detection results to help users understand whether their exposure is of concern.

Today, emerging PCEMs can detect a variety of chemicals including:

- **Combustion by-products:** Formed from the incomplete burning of coal, oil, garbage, or other organic substances. Many are linked to cancer.
- **Fragrances:** Added to personal care products, household cleaners, food products, and more. Some fragrances are toxic and persistent in the environment.
- **Flame retardants:** Added to textiles, electronics, foam-based furniture and other produces to reduce flammability. Despite health concerns and questions regarding efficacy, widespread use continues.
- **Isocyanates:** Industrial chemicals used to manufacture materials such as spray foam insulation, automotive paints, and flexible foams used in items like upholstery and mattresses. These chemicals are known to cause occupational asthma.
- **Pesticides:** Designed to kill, repel, or mitigate pests like insects, rodents, weeds, and microorganisms. Human health impacts range from brain impairment to acute organ toxicity.
- **Plasticizers:** Used to impart flexibility to plastics, such as polyvinylchloride (PVC). Phthalates, a common group of plasticizer chemicals, are associated with adverse reproductive and neurological development.
- **Volatile organic compounds (VOCs):** Emitted from oil and gas production and used in new building construction and everyday consumer products. Many VOCs can contribute to cancer, respiratory irritation, and neurological effects.

STUDY OVERVIEW: CHARACTERIZING THE DEMAND FOR PCEMS

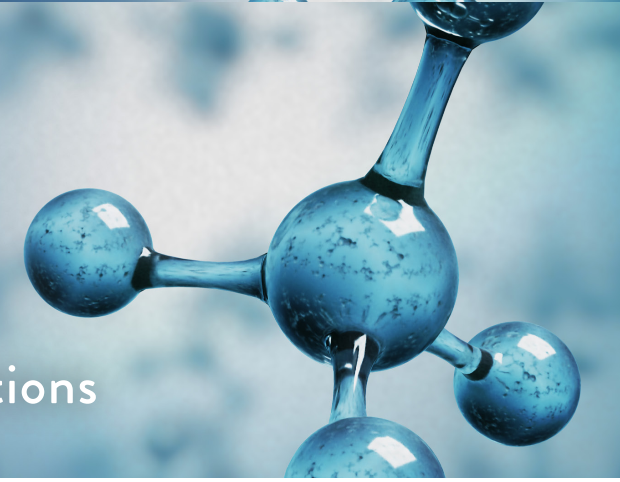
A critical question developers and investors have concerning PCEMs is their market potential. Until now, little was known about whether consumers would purchase such technologies, which features or capabilities they value, and what they would be willing to pay.

To help characterize and quantify the existing demand for PCEMs, EDF:

- **Surveyed 616 individuals** about their willingness to pay for PCEMs and the device features that matter most to them through a "choice experiment."
- **Conducted 16 expert interviews** with stakeholders across the PCEM supply chain to better understand the market challenges and opportunities that exist for these products.

This report details the results of the willingness to pay survey and expert interviews with the goal of providing insights about the market potential for PCEM technologies for key market players, such as technology developers and investors.

Section 2 details the methods and results of the willingness to pay survey. For the interviews, we conducted in-depth, 45–60-minute phone interviews with each expert, which included 1) eight PCEM or analogous technology product developers; potential institutional customers or other users; and investors, and 2) eight experts in workplace chemical exposure monitoring, including industrial hygienists and labor representatives. Insights from the former are highlighted in "Interview Spotlights" throughout the report, and insights from the latter are summarized in Section 3, "PCEMs in the Occupational Setting," which draws on themes from all of the interviews focused on traditional workplace monitoring.



2 | THE CONSUMER PCEM MARKET
Willingness to Pay and Reactions

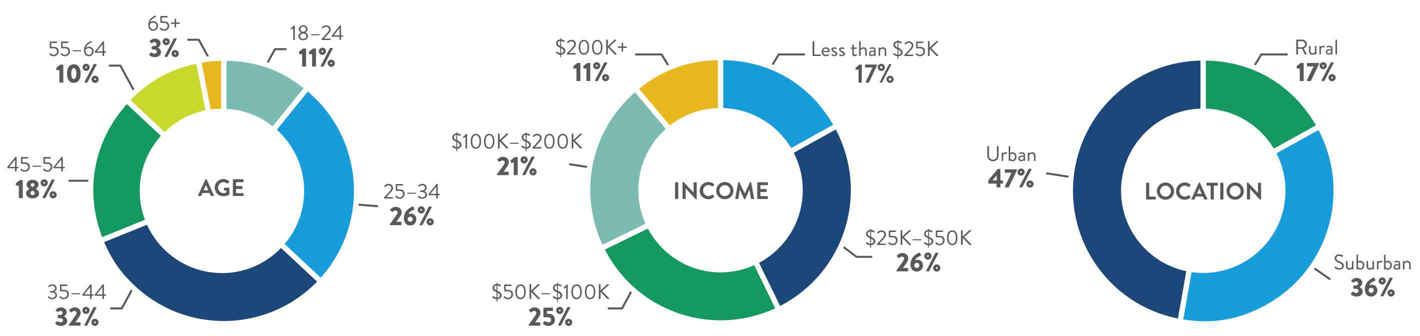
To better characterize the consumer market for PCEMs, we conducted a choice experiment survey with a nationally representative sample of 616 people. We asked respondents to consider a hypothetical decision to purchase a PCEM, presenting them with two devices differing in features and price. Respondents could indicate their willingness to purchase one or the other device at the stated price, or neither device. By systematically varying the device features and prices across respondents, we were able to estimate how much people were willing to pay for specific device features. The text box on the next page describes the types of device features evaluated in the survey. A separate technical report contains details about the study methodology as well as more extensive analysis and discussion of the results.

Among the survey respondents, 53% were male and 47% were female; Figure 2 and Figure 4 provide additional demographic information for the subset of respondents included in our analysis.*

OUR CHOICE EXPERIMENT

A choice experiment is a research method that measures the relative value that people place on different aspects of something. In our market study, we were concerned with understanding how people value different features of a PCEM. Designing our choice experiment involved deciding what device features to include, varying those features to create hypothetical devices, and then asking respondents to choose between a pair of devices with different features. Our survey evaluated 24 devices presented as 12 device pairs. Each respondent was presented with two pairs of hypothetical devices and was asked to choose a preferred device from each pair. For the survey, we developed hypothetical devices that we felt were realistic representations of potential devices that could enter the market in the future. This study design ultimately allowed us to calculate willingness to pay for 216 hypothetical device configurations.

FIGURE 2 | Key Demographics from the Consumer Survey



As part of the survey, we asked respondents how confident they were in their responses to the questions we asked about the values they place on device features; we used only data from respondents who said they were “very confident” in their responses (as opposed to “somewhat confident,” “somewhat unsure,” or “not at all confident”). This resulted in a final sample size of 304 respondents.

DEVICE FEATURES INCLUDED IN THE CHOICE EXPERIMENT

- **Type of device**—Is the device wearable or is the device one that requires biomonitoring (e.g., blood or urine samples)?
- **Timeliness of results**—How long does it take to receive results? Survey options included receiving results immediately, in a week, and in a month.
- **Number of scans**—How many scans or readings does the device provide? Survey options included unlimited scans, one scan per week, one scan per month, and one scan per year.
- **Number of chemicals**—How many chemicals can the device detect? Survey options included getting information on 200 chemicals, 30 chemicals, or "just a few chemicals."
- **Nature of results**—What type of information does the device provide? The survey options included 1) a simple yes/no indicator on whether exposure had occurred, 2) quantified exposure level information, or 3) quantified exposure level information coupled with additional interpretation (e.g., exposure is of low, medium, or high concern).

OVERALL WILLINGNESS TO PAY

Using standard statistical methods, we were able to estimate the willingness to pay (WTP) for each device feature evaluated. These WTP values reflect how the presence or absence of certain features alters what people are willing to pay for a device (see Table 1). Positive values indicate that, all else equal, respondents are willing to pay more for devices with a given feature. Conversely, negative values indicate that, all else equal, respondents are willing to pay less for devices with a given feature. This analysis allows us

INTERVIEW SPOTLIGHT

MARTY MULVIHILL, PhD
General Partner, Safer Made

Safer Made is a venture capital firm that works to identify technologies and products that are inherently safer, reduce chemical exposures, and are less impactful on the environment.

Do you see a clear demand in the market for PCEM devices?

"I believe there is demand for chemical exposure information on behalf of the consumer. It's all part of the larger health and wellness trend, and chemicals are a big part of it. An exposure monitoring device would be a great tool for consumer empowerment that can drive huge shifts in the marketplace."

What might a successful PCEM product look like?

"Our firm has seen a number of environmental sensor-type technologies, but we are often disappointed with the amount of data you can get from them. A device that can cover a broad spectrum of chemicals and that provides simple, understandable results at a reasonable price point would be very attractive—we just haven't seen that yet. Alternatively, a device that detects a targeted set of chemicals of interest to a particular consumer segment could also have market success. Ultimately, what's needed is a 'compelling story' of an easy-to-use, low-cost sensor that gives actionable feedback to the consumer."

How confident are you about the future of the PCEM market?

"Overall, I'm pretty convinced that, done well, a device that provides more information about the chemicals in our daily life will drive changes in consumer habits. And if you can capture that change in consumer habits, there is your way to monetize it."

to draw some conclusions about what people value in potential PCEMs:

- **Device type:** Overall, respondents preferred wearable devices to biomonitoring services, but this difference was small compared to differences observed with other features.
- **Timeliness of getting results:** Respondents considered receiving immediate results a significant benefit and were willing to pay, on average, an additional $154.37 for devices with this feature.
- **Number of scans:** Respondents were willing to pay, on average, an additional $76.55 and $79.19 for devices that provide unlimited scans or scans once per week, respectively, and willing to pay less for devices that provide scans once per month or once per year.
- **Number of chemicals:** Respondents were willing to pay, on average, an additional $159.77 for devices that detect 200 chemicals and less for devices that detect only 30 chemicals or "just a few" chemicals.
- **Nature of results:** Respondents were willing to pay, on average, an additional $130.49 for devices that provide both an exposure level and interpretation of that exposure level. They were not willing to pay more for devices that provide only exposure level or only indicate whether chemicals are detected or not.

In general, it appears that respondents highly value "premium" device features—the features we expected respondents would favor the most. Premium features are denoted with a "P" in Table 1. We did not define a "premium" feature for the "type of device" feature category given that wearable devices and biomonitoring services are fundamentally different technologies.

Overall, respondents placed the most value on devices that detect a large number of chemicals and provide immediate results. The quantification of exposure levels paired with additional interpretation of detected exposure levels was the third most valuable device feature.

INTERVIEW SPOTLIGHT

MARC EPSTEIN

Co-Founder and CEO, MyExposome

MyExposome is a start-up company providing passive chemical exposure monitoring in the form of a silicone wristband worn by users. The wristband can detect over 1,000 chemicals and is based on technology developed at Oregon State University.

What have you heard from users about your company's PCEM device?

"Our research with general consumers tells us people have no problem using it properly. They unwrap the device, slip it on, and go about their daily activities. At the end of the monitoring period they send the wristband back to us, and we run a full analysis and send them the results. One of our challenges is that it remains unclear what a lot of the information we generate means to someone's current health. They want to know what the levels mean—is it bad for me? That's something we are working on."

What is driving interest in PCEMs and where do you see the market going?

"There is now greater awareness about the impact of chemical exposures on health. As that issue becomes harder to ignore, the demand for data in industrial settings and among similar large group settings will become unstoppable. Factories, first responders, armed forces, firefighters—people exposed to all kinds of unusual things. They will be the ones looking for devices like ours."

INTERVIEW SPOTLIGHT

JANIE SHELTON, PhD

Scientist, 23andMe

Dr. Shelton sees some key similarities in the technology and market between genetic testing and personal chemical monitoring.

What early steps helped build the market for direct-to-consumer genetic testing?

"Early on we invested in being a research-oriented company to establish our credibility and to drive this new market forward in a scientifically sound manner. We also invested in designing smart, accessible data-sharing platforms and educational materials to help customers interpret and understand the information generated from our product. Personal chemical monitoring would face a similar need for consumer education, so investments here will be critical in designing these types of products.

What steps did your company take to grow in size and become profitable?

"We invested in technology that allowed us to scale and lower the price of our product to become more accessible. In parallel, we prioritized a research platform where customers who consent could easily participate, which over time generated data which has become useful for discovering the underlying genetic basis for diseases and treatments, as well as behaviors, traits, and preferences. Many of these findings have been published in peer-reviewed journals, which feeds back into being able to return compelling results to our customers on a wide range of topics."

What potential do you see for the PCEM market in the coming years?

"We've seen a huge explosion in consumers interested in learning about their health. Consumers today want control. With genetic testing, they get compelling, actionable information they can take to a doctor to discuss screening. In the same way, monitoring for environmental chemical exposures could be very actionable. There is increasing awareness of how different environmental factors might impact health, and a device that monitors chemical exposure could fill what is currently a complete void in marketplace."

TABLE 1 | WTP Estimates by Feature

CATEGORY	FEATURE	WTP*
Type of Device	Wearable	$28.47
	Biomonitoring	-$28.47
Timeliness of Results	Immediate (P)	$154.37
	One week	-$8.44
	One month	-$145.93
Number of Scans	Unlimited (P)	$76.55
	Once per week	$79.19
	Once per month	-$87.08
	Once per year	-$68.67
Number of Chemicals	200 (P)	$159.77
	30	-$21.27
	Just a few	-$138.50
Nature of Results	Exposure level & interpretation (P)	$130.49
	Exposure level	-$7.84
	Detect only	-$122.65

**See the technical report for statistical significance information on each WTP estimate.*

WILLINGNESS TO PAY BY DEMOGRAPHIC CHARACTERISTICS

We also examined how different demographic groups valued each device feature. We looked separately at women and men; respondents younger and older than 45 years of age; respondents who said they or their partner/significant other were pregnant, planning to get pregnant within the next year, or had a child in their home; and respondents who self-reported as being exposed to chemicals at work. Figure 3 summarizes these groups' WTP for individual device features, organized by features that a particular group valued the most. In the figure, each "$" represents $25. Per the design of choice experiment surveys, it is not possible to add up individual WTP values across device features to estimate how much a group would pay for a whole device.

FIGURE 3 | WTP by Demographic Groups

WOMEN

200 chemicals	$$$$$$$$$
Immediate results	$$$$$$$$$
Detailed results	$$$$$$$$
Unlimited scans	$$$$
Wearable devices	$

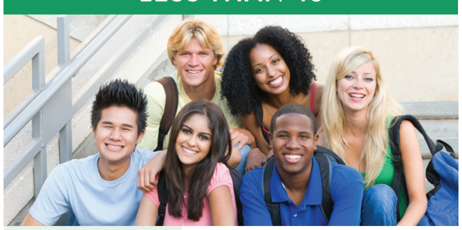
MEN

200 chemicals	$$$$$
Immediate results	$$$$$
Once per week scans	$$$$
Detailed results	$$$
Wearable devices	$$$

EXPOSED AT WORK

200 chemicals	$$$$$$$$$$
Unlimited scans	$$$$$$$
Immediate results	$$$$$$
Biomonitoring services	$$
Detailed results	$$

LESS THAN 45



200 chemicals	$$$$$$$
Immediate results	$$$$$$
Detailed results	$$$$$
Unlimited scans	$$$$
Wearable devices	$

45 AND OLDER

Detailed results	$$$$$$$$$
Immediate results	$$$$$$$
200 chemicals	$$$$$
Once per week scans	$$$$
Wearable devices	$

PREGNANT/CHILD IN HOME

Unlimited scans	$$$$$
200 chemicals	$$$$$
Immediate results	$$$$
Detailed results	$$$
Biomonitoring services	$$

In Figure 3, each "$" represents $25. Per the design of choice experiment surveys, it is not valid to add up individual WTP values across device features to estimate the WTP for a whole device. For examples of WTP for whole-device configurations, see Table 2.

WILLINGNESS TO PAY VALUES FOR EXAMPLE DEVICES

Employing specific statistical modeling, we determined the average total price people would be willing to pay for various hypothetical devices (see technical report for additional detail). Table 2 provides WTP estimates for four hypothetical PCEMs, combining various device features to demonstrate how differences in feature combinations affect the overall device value. These hypothetical devices do not reflect all possible feature combinations and are for illustrative purposes only.

Consumers' WTP for a PCEM varies by several hundred dollars depending on the combination of device features. The maximum WTP for a device is $459

TABLE 2 | WTP Values for Select Hypothetical Devices

	TYPE	TIMELINESS	SCANS	CHEMICALS	RESULTS	AVG. WTP
1	Wearable **Biomonitoring**	**Immediate results** One week One month	**Unlimited scans** One scan per week One scan per month One scan per year	200 chemicals **30 chemicals** Just a few chemicals	Exposure level and interpretation **Exposure level only** Detect only	**$80**
2	**Wearable** Biomonitoring	Immediate results **Results within a week** Results within a month	**Unlimited scans** One scan per week One scan per month One scan per year	200 chemicals 30 chemicals **Just a few chemicals**	**Exposure level and interpretation** Exposure level only Detect only	**$113**
3	**Wearable** Biomonitoring	**Immediate results** Results within a week Results within a month	Unlimited scans One scan per week **One scan per month** One scan per year	**200 chemicals** 30 chemicals Just a few chemicals	**Exposure level and interpretation** Exposure level only Detect only	**$293**
4	**Wearable** Biomonitoring	**Immediate results** Results within a week Results within a month	Unlimited scans **One scan per week** One scan per month One scan per year	**200 chemicals** 30 chemicals Just a few chemicals	**Exposure level and interpretation** Exposure level only Detect only	**$459**

In Table 2, the white boxes with bold text represent features selected for hypothetical PCEMs.

(device #4). Device #3, which differs from #4 only by the frequency of scans, has a WTP of $293. Devices #1 and #2, which have two premium features each, have WTP values of $80 and $113, respectively. Still other devices had a negative WTP, meaning that an average consumer would not buy it (see technical report for additional detail).

Overall, there were 70 hypothetical devices with an average positive WTP, generally relying on the presence of at least two premium features. Further, nearly 40 devices with hypothetical feature combinations would fall in the $100 to $300 range—price points where many other types of personal health monitoring devices reside.

CHARACTERISTICS OF RESPONDENTS WHO WOULD PURCHASE DEVICES

We also analyzed demographic differences between respondents who chose to select a device from the choice experiment versus those who opted not to select any device. We found that the following characteristics were associated with respondents being more likely to select a device to purchase:

- **Having a higher level of concern about chemical exposure:** Respondents who indicated they are most concerned about chemical exposure were ***3 times*** as likely to purchase a device compared to those with the lowest levels of concern about chemical exposure.
- **Having a larger number of medical conditions/ chemical exposure incidents:** Those who experienced the largest numbers of medical conditions or chemical exposure incidents were at least ***5 times*** as likely to purchase a device.
- **Having at least a college degree:** Respondents with college or graduate degrees were ***almost twice*** as likely to purchase a device.
- **Indicating they have healthy habits:** Those who indicated that they had several "healthy habits" were ***3 times*** as likely to purchase a device.

INTERVIEW SPOTLIGHT

ROMAIN LACOMBE, MS
CEO, Plume Labs

Plume Labs developed a personal air pollution sensor called Flow. The device, which went to market in 2017 and retails for $179, measures real-time concentrations of four major air pollutants.

What sort of feedback have you heard from users of your device?

"Our users tell us they like the simplicity of the device—they take it out of the box, charge it, connect it to their phone, and they're ready to go. They also like that the device works with their phone's GPS to show exactly where, when, and to what types of pollution they were exposure to."

What considerations went into the development of the device?

"One of the challenges was striking a balance between the data we could show the user, and what is actually useful in a given situation. We worked early on with a team of designers—conducting interviews with potential customers to develop a user-centric product and interface. Now, we're experimenting with icons that represent different levels of air quality. These visual representations give instant feedback, but also let the user drill down to see more and more information. Our approach allows Flow users to explore their data in the level of detail they choose. This also makes the device useful to researchers."

What do you see for the future of your device?

"Longer term users (and anyone else who is interested) will be able to tap into crowdsourced, community-level mapping data as adoption grows. This is something that our community members have been passionate about from the start. Actively mapping air pollution, street by street, has huge potential as a catalyst for action—people coming together to improve air quality at the local level."

INTERVIEW SPOTLIGHT

JOHN PETROZZA, MD
Director of the Fertility Center, Massachusetts General Hospital

Dr. Petrozza is a key collaborator on Harvard's Environment and Reproductive Health (EARTH) research initiative, one of the most comprehensive studies of how environmental exposures and lifestyle impact fertility.

How might you imagine a PCEM device being used in reproductive health care?

"In our studies, we collect urine and serum samples from patients at study entry and each time the patient comes in for fertility treatment. Having additional chemical exposure data would be welcome, as long as we know that the devices are reliable and can detect potentially very low levels of exposure. Devices would also need to be user-friendly, give feedback to the consumer, and provide a way to share data with healthcare providers."

Do you have any concerns about PCEM devices?

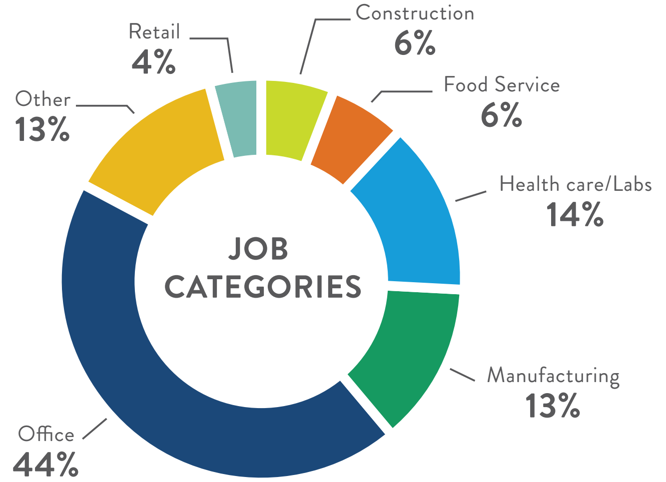
"From a consumer standpoint, I worry about panicking patients about exposures. We are all exposed to chemicals every day, and there are compounds you can't avoid small exposures to, but the consumer doesn't necessarily understand that. We would have to educate them that in many cases the goal is to minimize those exposures, not necessarily to avoid them."

How might PCEM devices affect public health more broadly?

"Environmental issues affect overall health, not just reproductive health. Depending on what these devices can measure, I think they're going to have a profound impact."

- **Being younger:** The youngest respondents were most likely to purchase a device; the likelihood of purchasing a device declines by 25% for each 10-year increase in age.
- **Being exposed to chemicals at work:** Respondents who reported being exposed at work were ***2.7 times*** more likely to purchase a device. Notably, the majority of individuals who self-reported being exposed at work were not employed in industrial settings (see Figure 4).

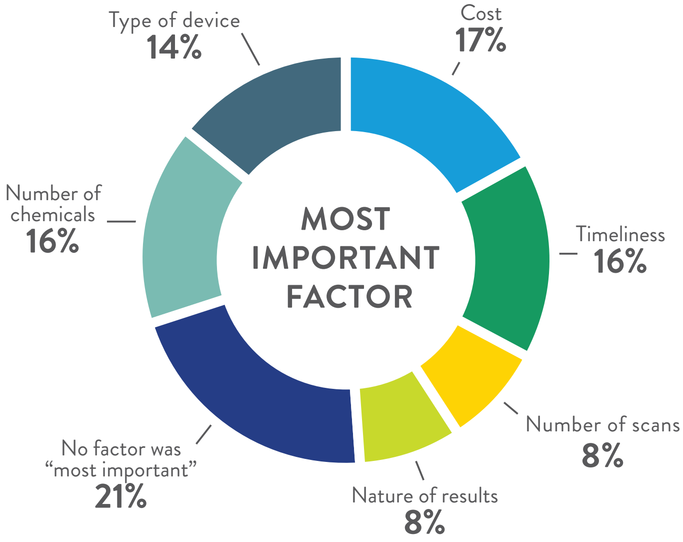
FIGURE 4 | Job Categories of Those Exposed at Work



FACTORS INFLUENCING PURCHASING DECISIONS

We also asked respondents what factor was most important in deciding which device to purchase (Figure 5 on the next page). There was no single feature that dominated the decision-making process. Importantly, cost was not the most important factor for most respondents (83%), indicating that price does not overly dictate PCEM purchasing decisions. Given that consumers have different priorities for PCEMs, there will likely be opportunities for various device types or configurations on the market.

FIGURE 5 | Most Important Factor in Device Selection



CONSUMER ACTION BASED ON INFORMATION PROVIDED BY PCEMS

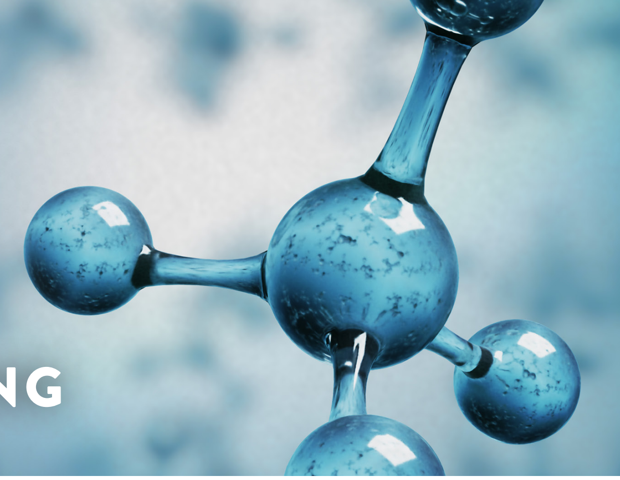
Following the willingness to pay portion of the survey, we asked participants, "If you had information on chemical exposure provided by these devices, what would you do with it?" The most common action-oriented responses—listed in order of frequency—included:

1. **Change behavior** in order to avoid chemical exposures.
2. **Share results with their doctor.**
3. **Share results with their network**, including telling friends/family or educating others.
4. **Research** the chemicals detected.
5. **Tell an official** (e.g., government official, poison control) or their employer.

Many respondents indicated they did not know what action they would take and others said they would do nothing, demonstrating the importance of consumer education efforts in the development of any future PCEMs. However, more respondents said they would take one or more of the actions listed above, indicating the potential for consumer-driven knowledge sharing and actions that would raise public awareness around everyday chemical exposure, encourage efforts to reduce hazardous exposures, and, ultimately, inspire more demand for PCEMs.

LOOKING FORWARD

It is important to note that the WTP results obtained from the survey are based on limited descriptions of hypothetical devices, communicated to survey respondents in an abbreviated manner. Presumably, as devices arrive on the market, they will be supported by consumer education campaigns. These efforts should better inform consumers about the device features and how they work, giving individuals a clearer picture about how the devices might be of interest or useful to them. Once the devices are on the market, consumer perceptions and values are likely to adapt.



3 PCEMS IN THE OCCUPATIONAL SETTING

Every day, workers across a wide range of industries are exposed to potentially hazardous chemicals on the job. Regulatory occupational exposure limits have been established for some chemicals, but these represent only a small fraction of all hazardous chemicals used in the workplace and often do not reflect the most up-to-date health studies.

Where exposure limits exist, employers may monitor chemical exposure to ensure compliance. To do so, they often must follow specific procedures and use specific types of equipment. Other types of occupational monitoring may be done to assess the effectiveness of exposure controls in the event of an incident (e.g., a chemical spill); in response to employee concerns; or if an employer wants to better characterize various exposure scenarios in the workplace. Some employers engage experts, known as industrial hygienists, to measure and evaluate chemical exposures in the workplace.

To explore the potential market for PCEMs in the workplace, EDF interviewed a number of industrial hygienists with experience monitoring for chemical exposures across a wide range of industrial settings (see text box to the right). Additionally, EDF interviewed organized labor representatives with occupational exposure monitoring experience, to gain insights on the impact of this market on workers. These interviews focused on wearable external monitoring devices.

> *"Today a big question is, 'How many [chemical] samples can I afford to take?' If you can give me a broader set of information for lower cost, it will change that equation."*
>
> **—INDUSTRIAL HYGIENE CONSULTANT**

Workplace monitoring experience represented among industrial hygienists and labor representatives interviewed:

- Fiberglass manufacturing
- Hazards waste site cleanups
- Hospital operating rooms
- Building materials manufacturing
- Military equipment maintenance
- R&D laboratories
- Wastewater treatment plants
- Foundries
- NASA (International Space Station)
- Steel mills
- Metal plating operations
- Computer manufacturing

SHORTCOMINGS OF TRADITIONAL CHEMICAL MONITORING THAT PCEMS MAY RESOLVE

- Traditional sampling targets small sets of specific chemical compounds, typically those with regulatory occupational exposure limits. This conventional approach may miss other important chemical exposures—ignoring the full universe of real-world occupational chemical exposures.
- Traditional workplace monitoring captures just a snapshot in time, and it is difficult to know if this is representative of "normal" operations or exposures.

- Existing wearable monitoring devices are often cumbersome and difficult for workers to wear. Further, workers often have to wear multiple devices to track different chemical exposures.
- Traditional monitoring conducted by an industrial hygienist can be disruptive to operations and present logistical challenges. For example, if monitoring is periodic, certain commonly used instruments must be packed, transported, unpacked, and calibrated.

EMERGING OPPORTUNITIES FOR PCEMS IN THE WORKPLACE

Experts identified various opportunities for PCEMs in the occupational setting, whether as a complementary tool to alleviate the complexities of traditional monitoring or to fill a gap in current exposure monitoring:

- **Broad screening to identify what chemicals are present where the specific chemical situation is unknown.** An example might be an indoor air quality situation where there are complaints and workers are getting sick, but the chemical source is not obvious.
- **Responding to an emergency** (e.g., chemical release or spill). Wearable devices may enable the identification of chemicals to which workers responding to an emergency are exposed.
- **Monitoring in situations that are currently logistically- or cost-prohibitive for traditional monitoring.** This could include monitoring workers in remote locations or those who work onsite at another employer's location.
- **Incorporating "total worker health."** Some employers are expanding their concern for workers beyond the workplace. PCEMs could be offered to employees as a way to help understand their chemical exposure both at work and outside the workplace.
- **Allowing less experienced individuals to implement monitoring.** This may only be possible for certain types of monitoring—such as screening—but easy to use PCEMs could alleviate some of the challenges associated with deploying industrial hygienists and complex instrumentation.

INTERVIEW SPOTLIGHT

LAUREN RIGGS
Regional Facilities Manager,
Google San Francisco

Ms. Riggs oversees strategic site planning operations and culture at Google's San Francisco campus.

How does Google think about chemical exposures and worker wellness?

"One of our responsibilities is employee health and wellness, and we prioritize good air quality within that. We have been impacted recently by poor outdoor air quality due to wildfires near the Bay Area. Some of our employees raised the issue of how the fires were affecting air quality in our buildings and wanted to know what we were doing. Beyond taking steps to manage the air quality inside our buildings, one thing we feel compelled to do is educate folks about what they can do as homeowners or renters during a poor air quality event."

How could your team use data from PCEMs in the workplace?

"Currently, we do periodic air monitoring—we take 8-hour air samples every two years—but a marriage of different chemical monitoring strategies would be ideal. For example, we could pair a distributed system of air sensors across our offices with a subset of individuals using wearable PCEM devices. This would give us spatial and temporal distributions of chemical data that we could use to optimize air quality within our space."

"Smaller, quieter, more comfortable. Ideally the worker would barely notice it's on for 8 hours... And it should be at a price anyone could afford."

— UNION REPRESENTATIVE, EXPOSURE MONITORING EXPERT

INTERVIEW SPOTLIGHT

ANONYMOUS

Spokesperson for an international real estate developer

How does your company currently utilize chemical monitoring technologies?

"We do a lot of indoor air quality monitoring in our buildings. Typically, we are focused on VOCs because we have issues from off-gassing of paints, glues, furniture, and other materials. It comes up mostly in new buildings or tenant build-outs."

What hurdles to PCEM adoption do you see in the commercial real estate space?

"The cost of monitoring is not a barrier. A much larger issue is figuring out what to do with the information provided by these technologies, and whose responsibility it is to resolve issues if they are identified."

What value does monitoring create for your clients?

"We have some experience with this in China. They are putting up sensors all over, both outdoors and indoors. The driving force, of course, is outdoor air quality, which can be very poor in China. Landlords are using indoor monitoring to demonstrate that you are better off in their building. Where we put building monitoring in, we think landlords get higher rent, higher quality tenants, and ultimately make more money."

FEATURES OF AN IDEAL WEARABLE MONITORING DEVICE

Experts identified the following ideal features of a wearable PCEM in the workplace:

- Lightweight and convenient to the person wearing the device.
- Ability to provide results quickly, enabling immediate adjustments to the workplace, behavioral modifications, or other strategies to reduce chemical exposures (e.g., checking the air quality of a confined space to determine in real time whether it's safe to enter).
- A sufficiently long "shelf life" for devices that require laboratory analysis, especially for situations where the workers may be remotely located from a lab.
- Ability to identify timing and location of exposure. Examples of device features toward this end may include:
  - GPS to help map the worker's activities against detected exposures;
  - Automatic recording of when exposure begins and ends to allow for correlation between worker activities and chemical exposure;
  - An activity recorder with a time stamp, that allows workers to press a button and record notes about what he or she is doing at the time of exposure; and
  - Real-time exposure alerts/notifications, such as colorimetric reactions (i.e., changes in color to represent chemical detection or different detection levels).
- Ability to be worn in the appropriate location to best detect chemical exposure and not covered by protective gear:
  - Near the breathing zone for inhalation exposure (e.g., on the collar); and
  - Near hands, forearms, and any other exposed skin for dermal exposure.
- Ability to measure and record other environmental conditions, including:
  - Temperature and humidity: As some devices are sensitive to heat and humidity, measuring such environmental conditions would allow for results to be adjusted appropriately afterwards; and
  - Noise: Another important occupational hazard.

THE UNIQUE PERSPECTIVE OF ORGANIZED LABOR

Unfortunately, workers are generally unaware of what chemicals they are exposed to in the workplace, despite the fact that employers are obligated under the Occupational Safety and Health Administration's (OSHA) Hazard Communication standard to inform them. Many workers inaccurately assume that, if there is something hazardous, the government is doing or will do something about it. Broad availability of PCEMs may shift this dynamic, raising awareness of harmful chemical exposures and enabling better workplace interventions to reduce them. For example, widespread use of PCEMs may enable:

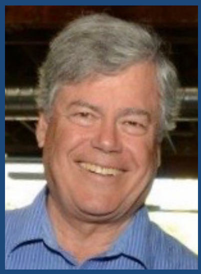
- **New standards:** Using PCEMs to monitor chemicals for which there are no current occupational exposure limits could eventually lead to the development of new standards.
- **Collective bargaining:** Through collective bargaining agreements unions can request chemical sampling from employers or the right to conduct their own sampling; however, today this is uncommon. If devices become smaller, cheaper, and easier to use, this may happen more in the future.

"The truth is that exposure limits have not been set for the vast majority of chemicals used in the workplace. Having knowledge about actual exposure levels could help organized labor push for more protective exposure limits."

—HEALTH AND SAFETY SPECIALIST, UNION FEDERATION

The unequal power dynamics between the worker and the employee raise some concerns with regards to worker privacy. For example, from a scientific perspective, a PCEM that has the ability to track workers' activities and tasks (e.g., via GPS) would enable better identification of the source of chemical exposure. Workers, however, may be suspicious of devices that track their location, because of the potential for misuse of such worker location data by the employer.

INTERVIEW SPOTLIGHT



TED SMITH, JD

Advocate and Founder, International Campaign for Responsible Technology (ICRT)

Mr. Smith's work focuses on environmental issues in the electronics industry. He also works with the Clean Electronics Production Network (CEPN).

What kind of features would be important to you in a PCEM?

"Better monitoring to alert workers when hazardous chemicals are present is really important. Right now, there doesn't seem to be one device that is both sensitive enough to detect exposures at relevant concentrations and also inexpensive enough to be feasible on a large scale. Also, it's common for us to see exposure to multiple chemicals that can together cause health problems, so a device that can monitor multiple chemicals is important."

Are there any developments that could drive more exposure monitoring?

"Nonprofit organizations like CEPN and Electronics Watch are supporting more workplace exposure monitoring in the electronics sector. CEPN is exploring more effective chemical exposure monitoring, for example by building requirements into a voluntary standard we're developing for companies that want to be at the cutting edge of addressing workplace health issues. Electronics Watch is advocating for worker protection from harmful chemicals exposures be explicitly included in electronics purchasing contracts. I do think there's going to be an uptick in the demand for monitoring, and part of that will include wearable monitors."

Could product certification programs in the electronics sector have an impact on chemical monitoring?

"Yes. One example is TCO Development, a Swedish non-profit organization that developed and manages a sustainability product certification for IT products, which includes provisions for hazardous chemical exposures in the workplace. I believe these types of programs are more likely to be a driver than new regulations—at least in the short term."

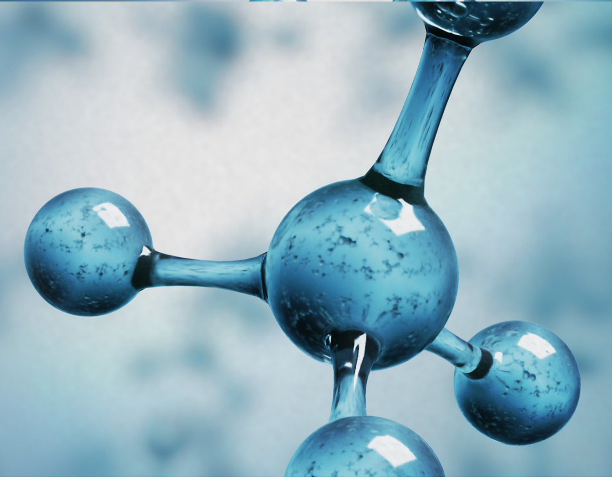
4 BARRIERS AND CHALLENGES TO PCEM MARKET GROWTH

While our research clearly demonstrates a demand for PCEMs in the consumer market and the occupational monitoring space, developing technologies that meet both consumer preferences and workplace monitoring needs will not be without challenges. Some of the barriers and challenges identified from this survey and the supporting stakeholder interviews include:

- **Cost:** Consumers expressed willingness to pay for devices priced in the low hundreds of dollars, but only for devices with premium features. It may prove challenging for PCEM developers to provide premium features at a low enough price, at least initially, when sales volumes are low.
- **Ease of use:** Consumers expect new technology to be simple to use, easy to connect (e.g., to their smartphone), and to deliver straightforward results. Users will prefer devices they can wear without drawing unwanted attention to their use and that do not inhibit normal activities.
- **Consumer education:** Consumer education and management of user expectations will be critical to the success of the PCEM market. It is likely to remain difficult to directly connect chemical exposure data with an individual's current health or future health outcomes, which is something that consumers will likely want to know. Technology developers will need to ensure that consumers understand the information provided by PCEMs but also their boundaries and limitations.
- **Identification of early adopters:** Technology developers will need to identify and target "early adopters" to seed the PCEM market toward ultimately building a large enough customer base to be profitable. This has been key to the success of other personal monitoring technologies.
- **Regulatory requirements:** Dependent on the device and particular application scenarios, technology developers will need to consider and adhere to regulatory requirements.
- **Validation:** Devices need to be reliable and validated according to an appropriate set of monitoring standards, especially devices intended for workplace monitoring. Conventional approaches to validating devices can ease adoption of devices in the workplace. However, devices without conventional validation may still provide value in the occupational setting if they are reasonably priced, well-designed, and provide a reasonable amount of accuracy for their intended use.
- **Flexible monitoring standards:** Monitoring standards for measuring chemicals in the workplace often specify the technology that must be used. Increased flexibility in such standards will be important for greater uptake of PCEMs in the occupational setting.
- **Employer considerations:** Employers will need to be prepared to act on information generated by PCEMs, including strategies for exposure reductions and establishing who may be responsible for such actions. Further, employers who use wearable PCEM technologies, especially those with GPS capabilities, will need to grapple with potential privacy concerns from workers.

Market entry barriers and challenges are certainly not unique to PCEM technologies. In fact, other monitored-self devices have encountered—and overcome—similar challenges to those identified here. For example, the direct-to-consumer genetic testing market faced regulatory hurdles, and certain fitness trackers have experienced challenges with privacy from their GPS functionality. Yet consumers' desire to have access to such information has ultimately prevailed.

Growing the PCEM market will require support and innovation from a variety of players—from investors and technology developers to researchers—to tackle technical and market challenges. But consumer experience with health and wellness self-monitoring devices already on the market, and the clear willingness to pay identified in this study, point to an exciting path forward.



5 | SUMMARY AND CONCLUSIONS

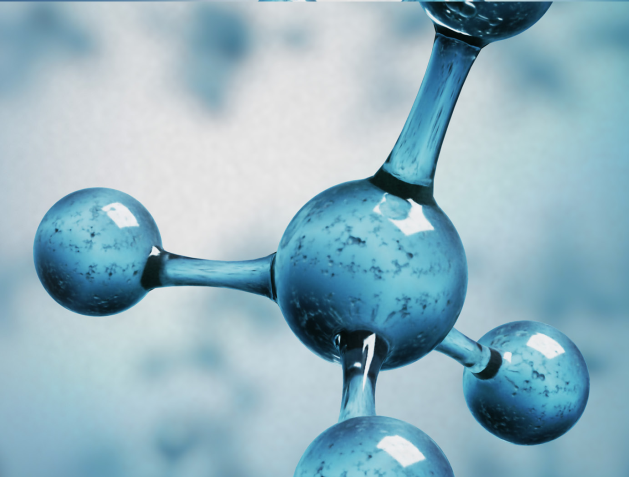
Our survey results provide some of the first quantitative evidence of consumer demand for devices that can monitor personal chemical exposures. Interviews with experts from across the supply chain affirm this demand and underscore the market growth potential for these technologies.

The willingness to pay survey found a clear consumer market for PCEMs. Nearly 40 hypothetical devices resulted in a willingness to pay between $100 and $300—a price range similar to the costs of successful personal health monitoring devices currently on the market. Consumers were also willing to pay, on average, $459 for a device that includes all surveyed premium features. Surveyed device features valued most were receiving 1) data on a large number of chemicals, 2) immediate results, and 3) information on both level of exposure and whether such exposure is of concern.

However, not everyone values PCEMs equally. Certain segments, including individuals who are younger, individuals who are college-educated, and individuals who self-report as having healthy habits, are more likely than others to purchase PCEM devices. Similarly, some market segments are willing to pay more than others for PCEM devices with premium features, including women and those who self-reported as exposed to chemicals at work.

Experts from companies like Google, 23andMe, and Safer Made (a venture capital firm), as well as technical experts from government and medicine, also point toward growing market demand for PCEMs—a demand that appears to be driven by increasing awareness of chemical exposures and their health impacts, as well as the simultaneous growth of the health and wellness technology market. Experts highlighted specific market opportunities for PCEMs and shared insights on how to address challenges facing the PCEM market today. Opportunities to accelerate broader PCEM market uptake included driving down cost, educating consumers, and identifying and targeting "early adopters" to build the market. Industrial hygiene and labor experts noted device features that would be particularly attractive within the occupational monitoring market, such as real-time exposure notifications.

Clear demand for PCEMs exists today and we anticipate the demand to increase over time. By measuring both consumers' overall willingness to pay for PCEMs as well as highlighting key insights from experts in the field, we hope to help entrepreneurs and technology developers better design and price chemical monitoring technologies toward creating a robust PCEM market. Entrepreneurs who can bring a viable personal chemical monitoring product into commerce have an incredible opportunity to claim part of a large and rapidly growing health and wellness technology market.



6 FURTHER READING & REFERENCES

For further reading about EDF's work on PCEMs, please see the following:

Catalyzing innovation in chemical monitoring
https://www.edf.org/health/catalyzing-innovation-chemical-monitoring.

Analysis Brief: EDF Year of Innovation
https://www.edf.org/sites/default/files/content/EDF_Year-of-Innovation_Analysis-Brief.pdf.

Summary of EDF Workshop, "Understanding Chemical Exposure, Accelerating the Market for Wearable Monitors"
https://www.edf.org/sites/default/files/content/EDF_Chemical-Exposure-Workshop-Summary.pdf.

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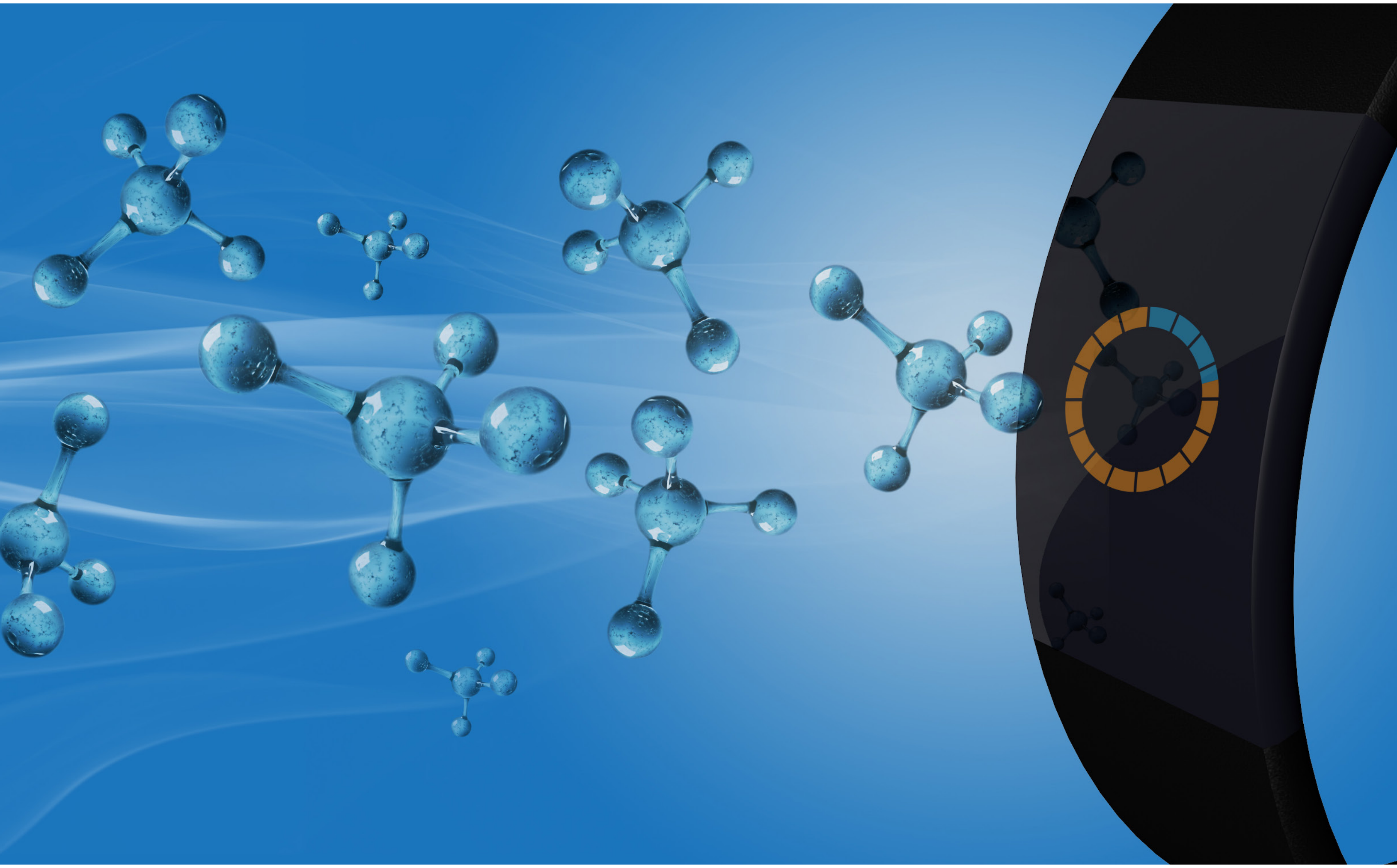

Finding the ways that work

JULY 2019