ARTICLE

BRINGING SUSTAINABILITY INTO THE LABORATORY

JENNY GIANNINI

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Resource Consumption

> Use your existing equipment more sustainably: Map freezer contents, regularly sort out old samples, defrost freezers, clean freezer coils, close fume hood sashes, and consider retrofitting legacy equipment.

> Consider decommissioning energy-inefficient equipment

> > Ex: UC Riverside saved $2,500, 25,000 kWh of energy, and 220,000 gallons [~830,000 liters] of water per year per autoclave by switching to more energy-efficient autoclaves[12].

> Make sure all lab members are properly educated about water purification systems. Water purification systems often require a large volume of feed water per liter of purified water produced[11].

> As a general rule of thumb: For each experiment, the lowest possible water purification grade should be utilized without compromising experimental results.

> Inform yourself about the energy requirements of your data storage and analytics: Careful choice of hardware (ie. cloud versus server computing platforms, memory usage, and processor options) and software (i.e.software versions) can help to reduce energy consumption[6,7].

> Participate in local equipment swaps or auctions. These venues may allow you to obtain well-performing equipment at a discounted price[16].

> Pre-order frequently used items in bulk to reduce the number of deliveries needed.

Waste Production

> Consider specialized recycling programs

> > Ex: Kimberly-Clark Professional recycling programs for protective clothing, nitrile gloves, and hand towels

> Make sure all lab members are properly educated about waste streams.

> Check whether your institute/company maintains a sustainable purchasing catalog, and if not, suggest that they do so.

Conference Travel

> Consider reducing your international air travel and/or attending conferences virtually [17].

Social

> Foster a healthy work-life balance: Lead by example, and honor non-working hours, weekends, and holidays.

> Set up a well-structured support system: Create a contact point where researchers feel comfortable addressing their work-related concerns and where measurable action is taken to address them.

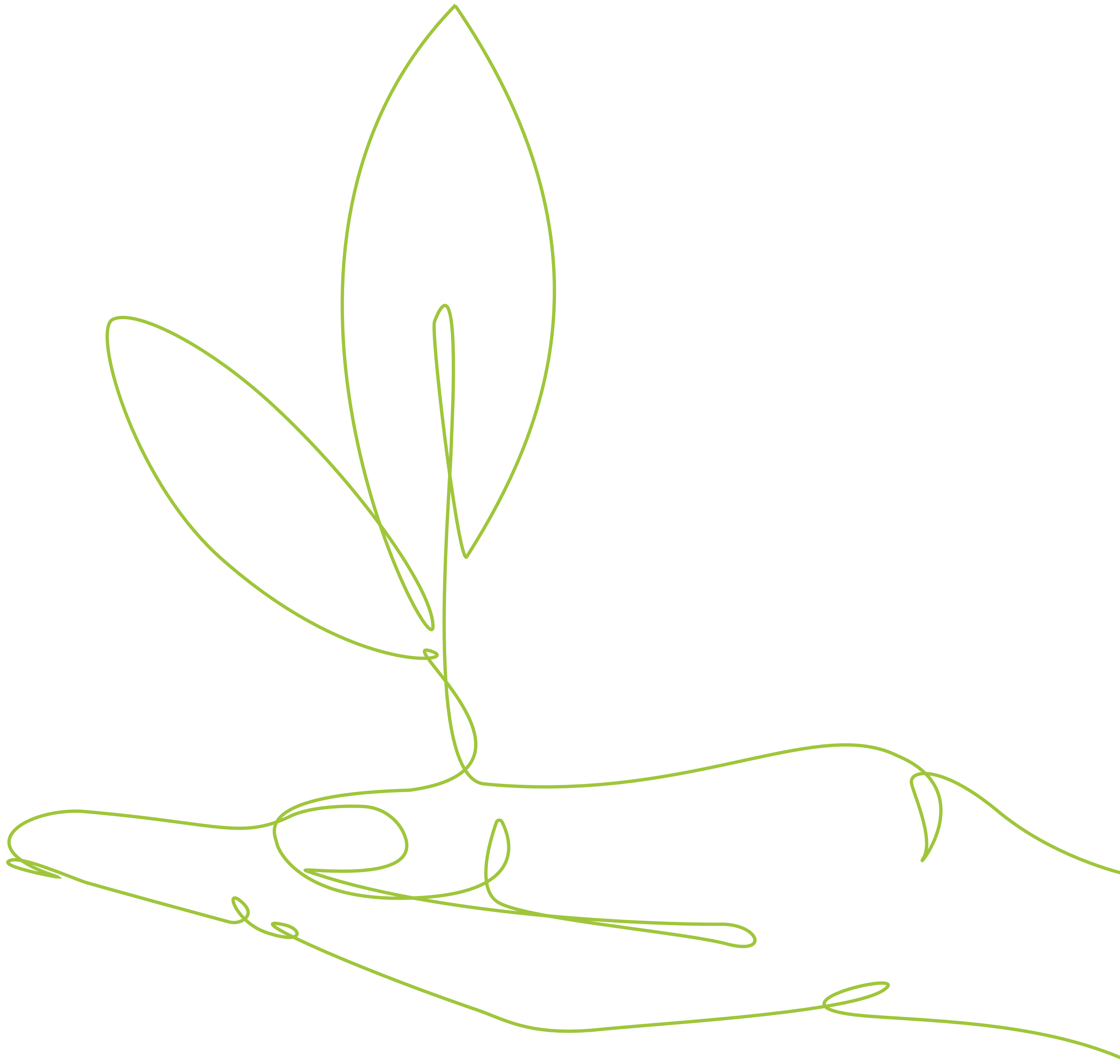
> Prioritize health and safety: Scientists are exposed to increased levels of hazards in the workplace. Ensure that your researchers are well-educated about the materials they are working with and that safety information is well-documented and accessible.

> Engage with your local community: Promote increased trust and transparency between scientists and the public.

SCOPE & IMPORTANCE

Whether you are a member of a small academic laboratory, leader of a large pharmaceutical company, or somewhere in between, we can all benefit from making our laboratory practices more eco-friendly. Besides helping to protect the environment, improving your laboratory's sustainability measures can also save money, improve inventory management and logistics, and provide a better working environment for your researchers.

It is also worth acknowledging that there are a variety of opinions when it comes to sustainability practices; ranging from those highly committed to laboratory sustainability to those who may still be skeptical that it is worth their time and effort. Regardless of where you fall on this spectrum, we want to provide an ecological and economic sustainability solution that will work for you. Here, we outline key facts and figures and provide guidance and implementation tips from scientists, sustainability consultants, and laboratory technology providers alike.



INTRODUCTION

Scientific research has enabled technological advancements, advanced human health, documented an amazing variety of biological species, and made countless other discoveries in just about every aspect of life. Furthermore, many scientists, by the nature of their work, become intimately aware of the stunning beauty and importance of our natural world.

Despite these positive aspects, research laboratories – paradoxically – are far from benign when it comes to their contributions to climate change. Laboratories are incredibly resource-intensive environments, requiring between 2.0 - 6.6 times as much energy as a traditional office building[1]. The cause of this massive energy requirement comes from laboratories containing large amounts of energy-intensive equipment, maintaining 24/7 operation, requiring extensive air filtration, and high airflow rates. Additionally, laboratories also produce large amounts of plastic, chemical, and biohazardous waste, and often have large and specialized logistical needs[2].

To address these issues, we'll first review in more detail some of the major dimensions of laboratory sustainability: energy and resource requirements, waste production, logistics, and social sustainability. All of these aspects contribute to the overall environmental impact of laboratories and can, therefore, bear room for improvement. Next, we'll identify some of the common barriers currently hindering laboratories from becoming more sustainable and provide strategies necessary to break those barriers. Then, we summarize the major benefits, along with a few potential drawbacks, of becoming more sustainable, and provide you with an easy-to-follow guide on how to start and stay with your sustainability journey. Lastly, we describe Labforward's standpoint on sustainability and ways in which we're here to help and become more environmentally conscious together.

DIMENSION OF SUSTAINABILITY

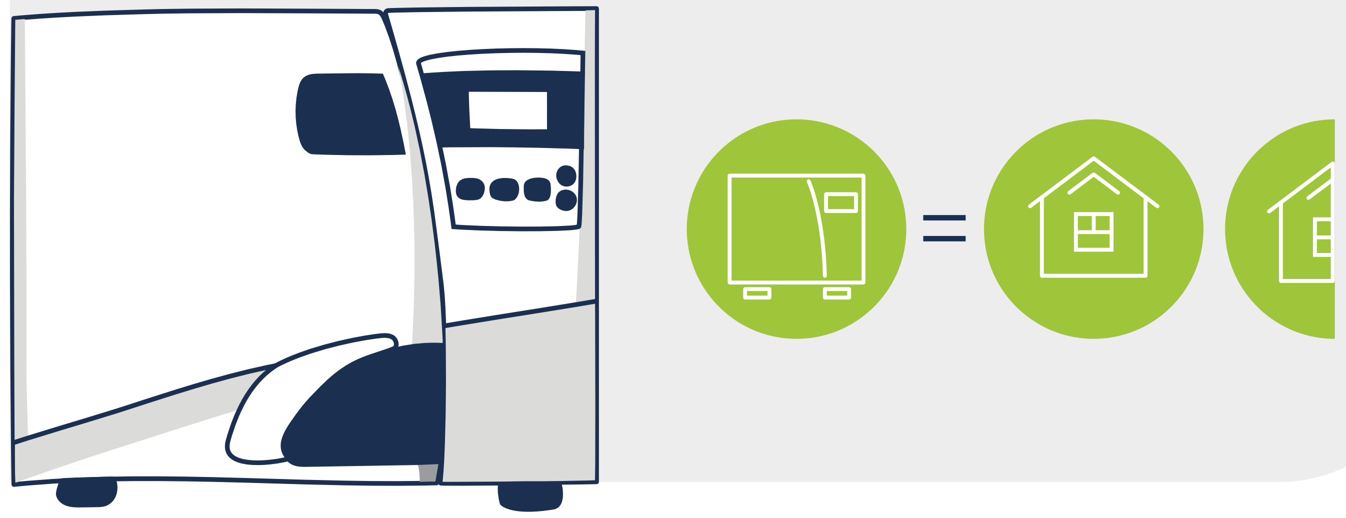
RESOURCE CONSUMPTION

Energy consumed by laboratory devices

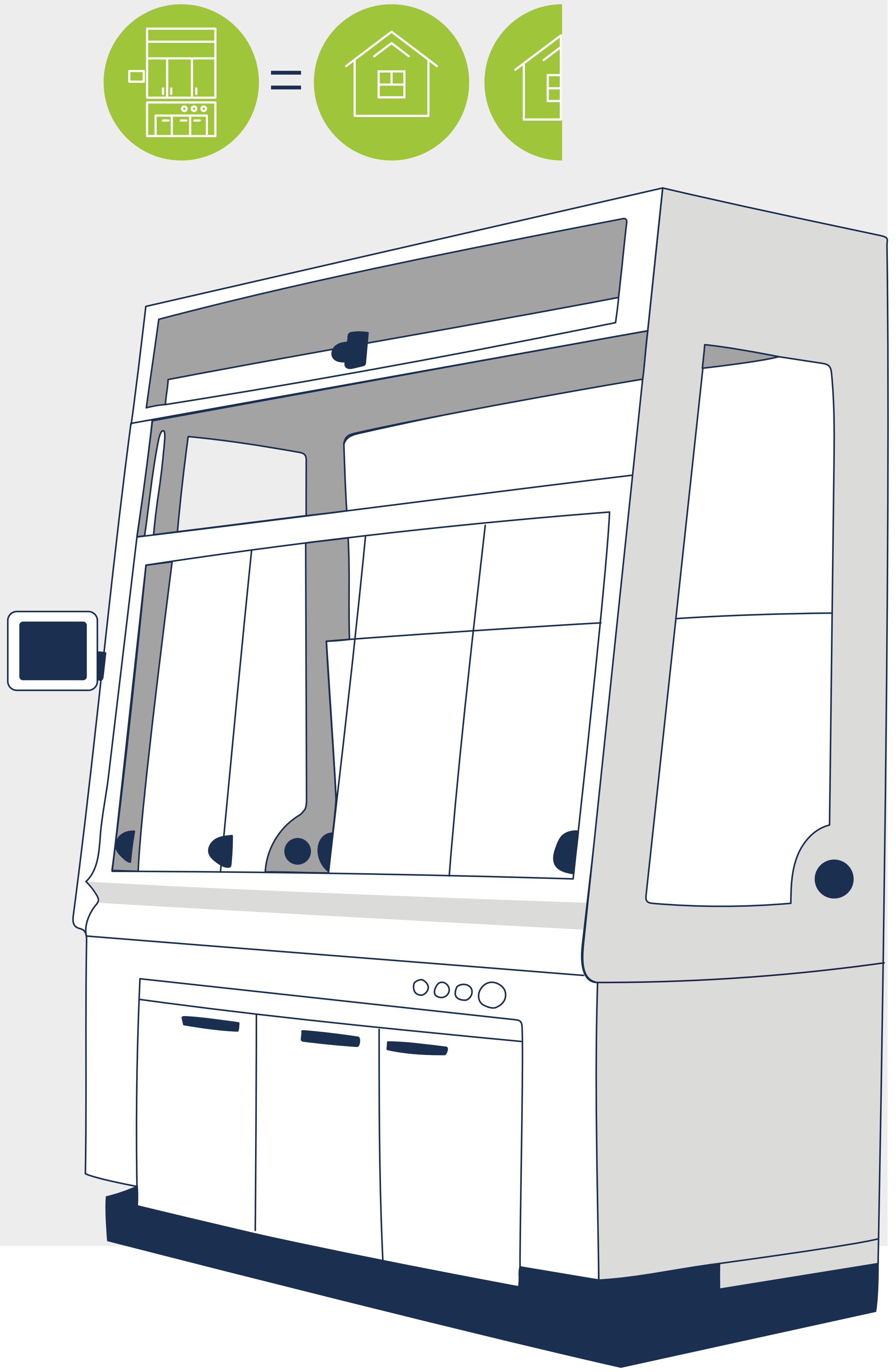
A joint project, developed by California utility companies' Emerging Technology Program and conducted by Allison Paradise from MyGreenLab, collected energy usage data from device manufacturers for common laboratory equipment, and survey results from California laboratories regarding the equipment density in their laboratories[3]. Together, this data can be used to estimate the cumulative energy consumption of a laboratory's common devices. To make these data more relatable, we've compared these values to the energy required by an average single-family home[4], then converted them to a "number-of-households-worth" of energy.

Perhaps among the most shocking of these data, is the energy required by single devices such as fume hoods, autoclaves, and ultra-low-temperature (ULT) freezers, both due to the amount of energy required and the prevalence of these devices in most common research laboratories.

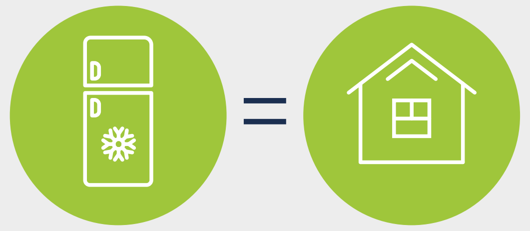
One **average autoclave**, for example, requires about **1.6 family households** worth of energy **per year** (or 17,212 kWh/Year).

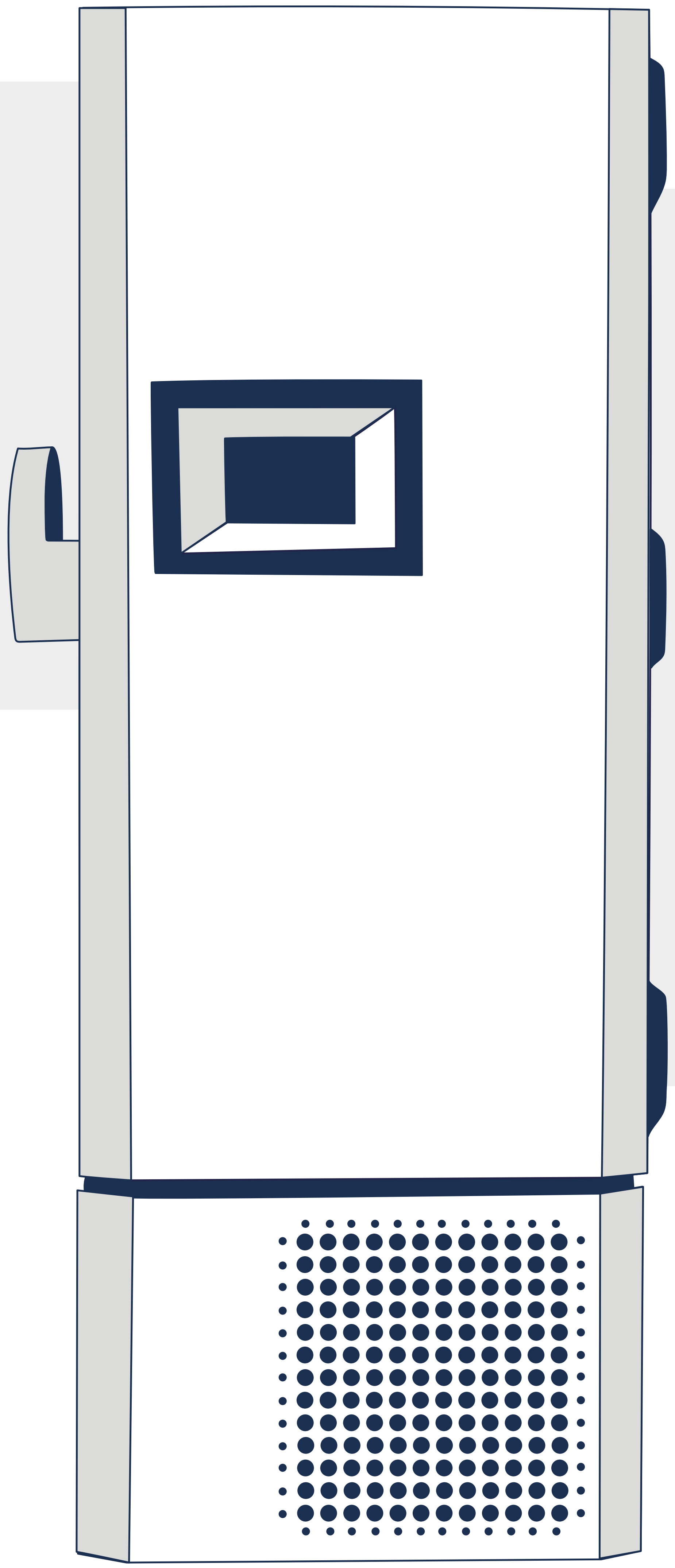


Similarly, an **average fume hood** requires about **1.5 family households** worth of energy **per year** (or 16,425 kWh/Year).

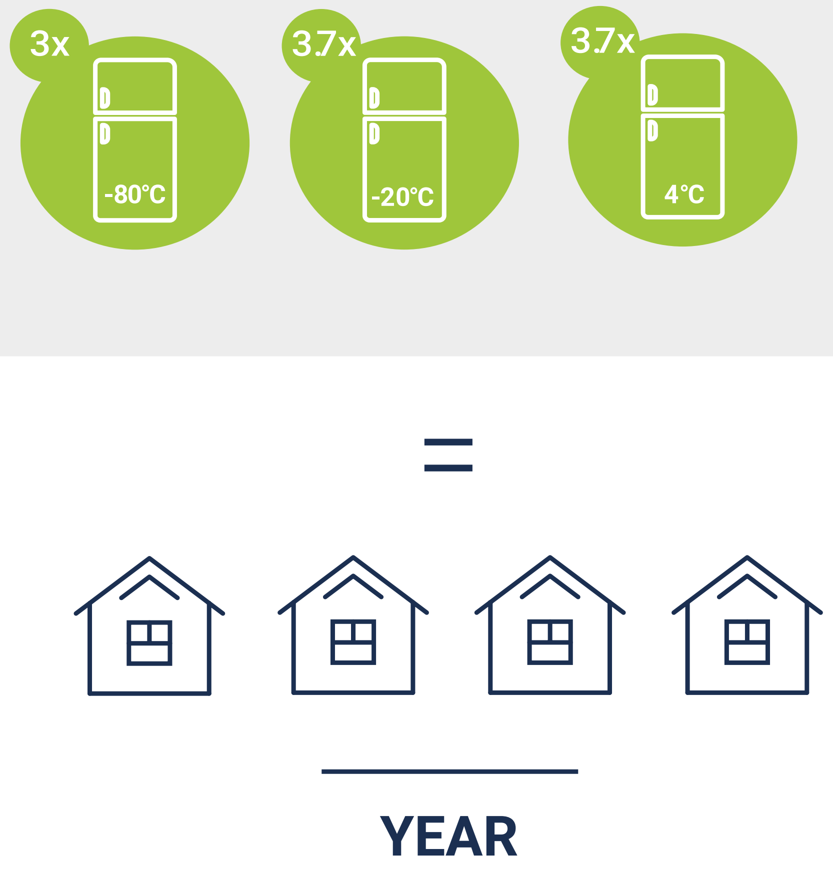


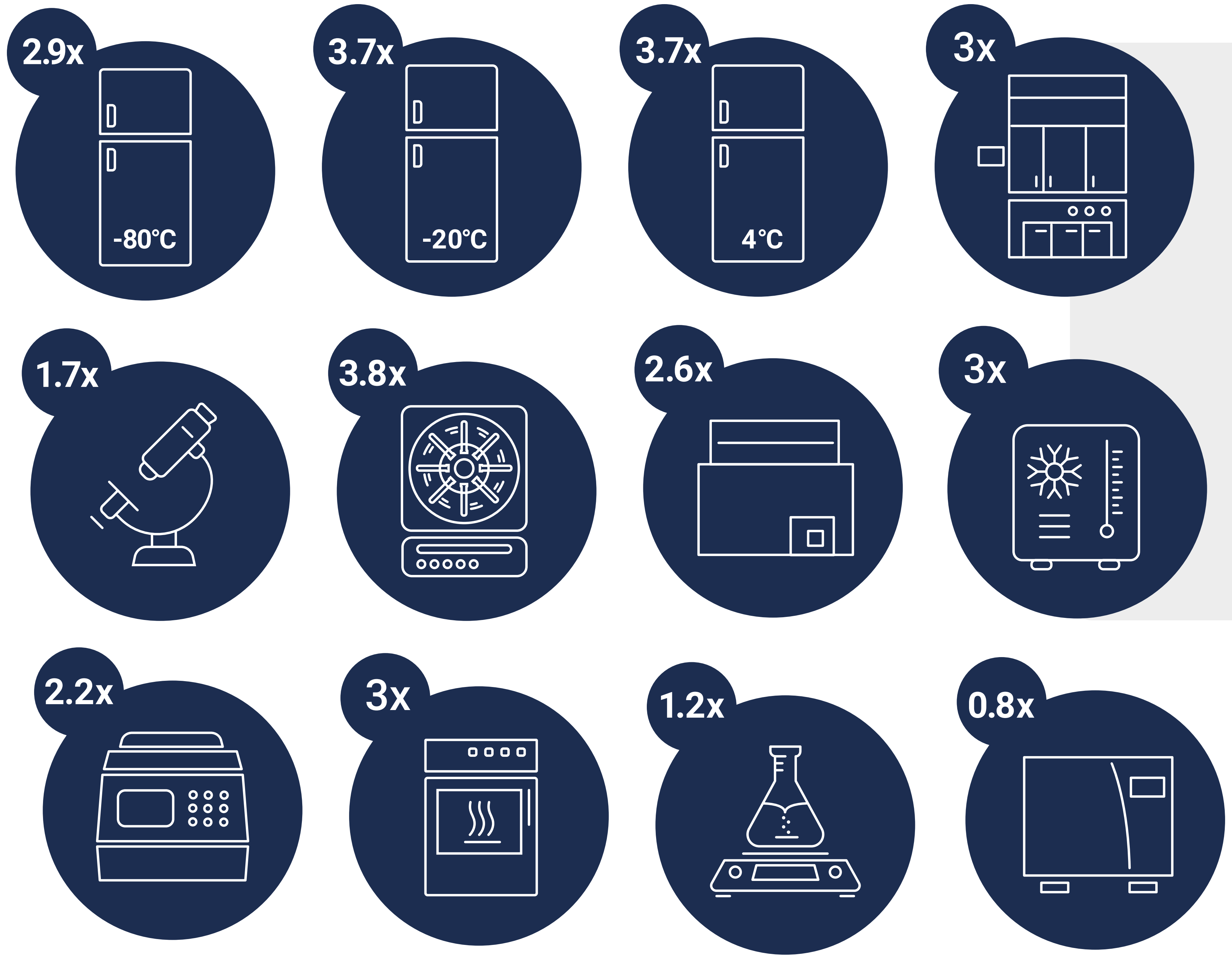
A **single ULT freezer** can require up to as much energy as a **family household per year** (or 8,783 kWh/Year).





Even if we only consider the cold storage equipment of an **average laboratory** (3 ULT freezers, 3.7 -20°C freezers, and 3.7 4°C refrigerators), this still equates to a huge amount of energy – about **4 family households** worth or 42,956 kWh/Year.





Finally, considering the equipment density of a **laboratory's common instruments** (including cold storage equipment, fume hoods, fluorescence microscopes, centrifuges, water baths, heating blocks, PCR machines, incubators, shakers, autoclaves, vacuum pumps, and tissue culture hoods), all of these devices amount to a surprising **14.2 family households worth of energy per year.**

Of course, these values can vary considerably when accounting for the specific make and model of a laboratory's equipment, specific equipment densities, device usage, and other factors, but needless to say, the amount of energy consumed by a laboratory's equipment is a large contributor to a laboratory's overall environmental impact.

Energy consumed by computational research

Experimental equipment requires large amounts of energy, as does computational research which relies on an extensive computational infrastructure usually consisting of servers, storage devices, and operating and cooling equipment. The electricity usage of data centers and high-performance computing clusters already exceeds the electricity consumption of entire countries and is projected to continue to rise in our data-driven society[5]. While scientific computational researchers are far from the only ones necessitating this massive energy requirement (other contributors include far less important data sources like Facebook selfies and mining Bitcoin), there are still steps informaticians can take to minimize their environmental impact.

By switching software versions, researchers can reduce the carbon footprint of this analysis by

73%

In a study conducted by Grealey et al. on the carbon footprint of bioinformatics research, the carbon footprint for a wide range of bioinformatic analyses was calculated. The researchers show that both careful choice of hardware (ie. cloud versus server computing platforms, memory usage, and processor options) and software (i.e. software versions) options can help to reduce energy consumption. For example, computational pipelines used for genome-wide association studies (GWAS), which help scientists identify genetic causes associated with a particular disease, can be quite resource intensive. One such computational pipeline, called Bolt-LMM, produces 17.29 kg of CO_2 emissions by running Version 1.0 of the software, while Version 2.3 produces only 4.7 kg of CO_2 emissions. Therefore, just by switching software versions, researchers can reduce the carbon footprint of this analysis by 73%[6].

There are even calculators researchers can use to quantify the environmental impact of their analyses[7].

Water consumption

Not only do laboratories require huge amounts of energy, but they also require significantly more water than standard commercial buildings of comparable size. The reasons for this increased resource demand are manifold: due to laboratories containing specialized equipment and requiring highly controlled environments to maintain experimental conditions (i.e. to avoid large temperature fluctuations), many laboratories have large cooling needs[8]. Additionally, both a laboratory's equipment and its waste often require sterilization (via autoclaves).

Furthermore, many experimental procedures require purified or ultra-purified water. For this reason, complex water purification systems are present in most laboratories and there are several types of water available to scientists at any given time[9].

Tap water, while safe for human consumption, contains impurities such as dissolved gases, dissolved organic matter, ions, and non-ionizing electrolytes[10]. Any impurities present in the water may compromise experimental results, with failed experiments leading to a waste of both time and resources. Therefore, the correct choice of water in an experiment is of great importance. Highly sensitive experiments, (ex: genomics, proteomics, cell culture, and chromatography) require ultra-pure water, while less sensitive procedures, (ex: media, buffer, and reagent preparation, water required for equipment – water baths, incubators, etc.), require purified water (but not ultra-purified water). Depending on the required water purity, a combination of treatment methods may be needed, including reverse osmosis, distillation, filtration, deionization, and ultraviolet treatment.

Generally, with higher water purity, comes a more varied and complex combination of water treatment methods[9]. For example, a more efficient laboratory water purifier (Merck Millipore's Elix® 3 – which combines reverse osmosis, deionization, and ultraviolet treatment) requires 5 liters of feed water per 1 liter of purified water produced, while a more inefficient model (Thermo Scientific Barnstead Mega-Pure MP-3A – utilizing distillation) requires 8 liters of feed water per 1 liter of purified water produced[11]. Therefore, laboratories should carefully consider the ratio of required feed water to water produced when choosing a water purification system.

Regardless of the choice of water purification system, researchers should also be committed to informing themselves about which experimental procedures require which water purity level. Since researchers tend to care deeply about the outcome of their experiments, they may tend to opt for more purified water than is truly necessary, without considering the environmental costs. In other words, always choosing ultra-pure water is neither an economical nor a sustainable choice. As a general rule of thumb: for each experiment, the lowest possible water purification grade should be utilized without compromising experimental results. The correct choice of water can be a simple way to reduce the environmental impact of conducting research and water purification providers can often advise on which purification grade should be used for a particular experiment.

Sterilization, usually via autoclaves, is also a highly water-intensive process. A study conducted by the University of California Riverside determined that each of their campuses' autoclaves was using approximately 700 gallons of water (about 2,650 liters) per day, much of which was used while the machines were sitting idle. As a result of this study, the University of California Riverside replaced its medical-grade sterilizers with more efficient research-grade sterilizers and found that the more efficient autoclave used 81% less energy and 93% less water while being equally effective[12]. If replacing old inefficient equipment is not financially feasible, old autoclaves may alternatively be retrofitted for a cheaper water-saving option[13].

California Riverside replaced its medical-grade sterilizers with more efficient research–grade sterilizers and found that the more efficient autoclave used

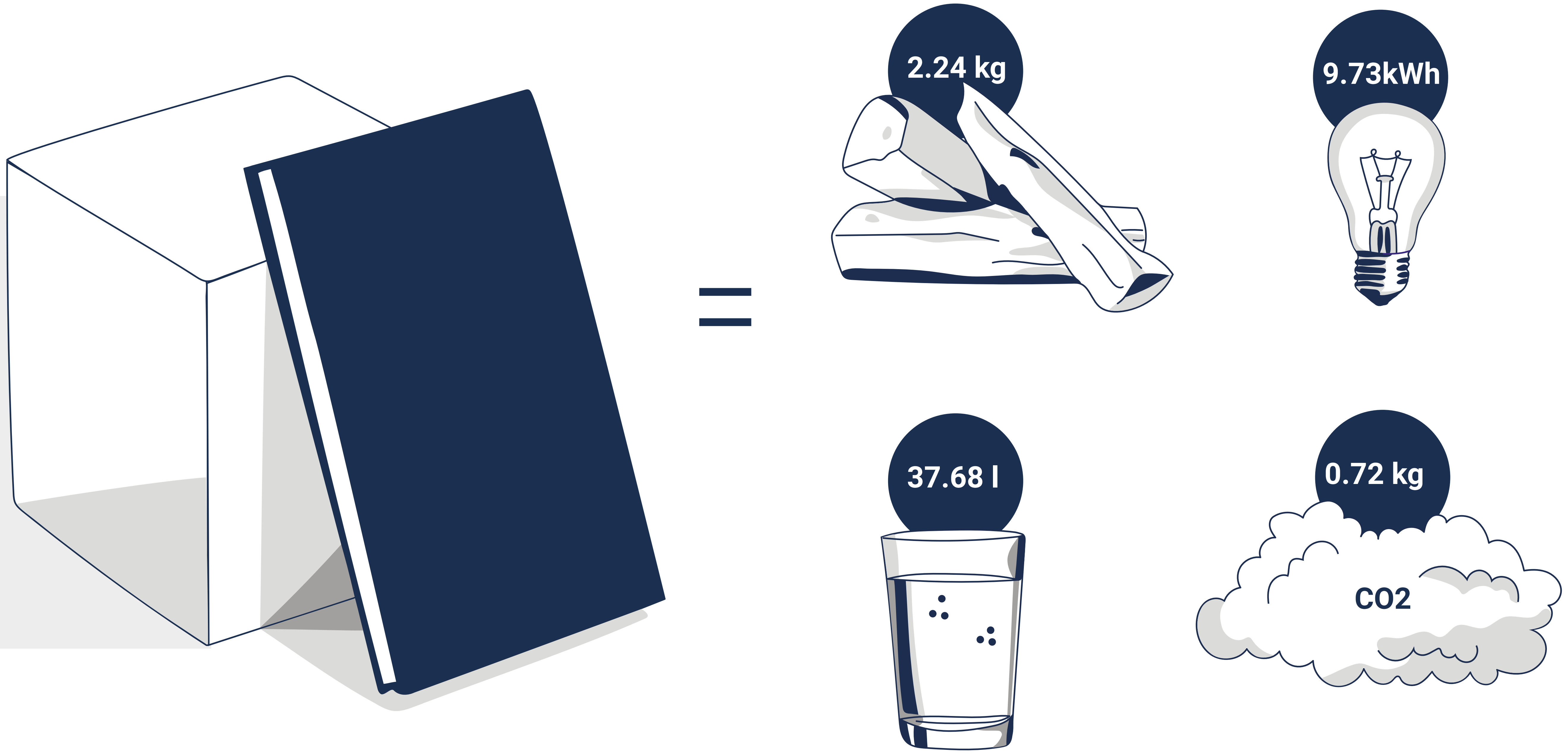
81% less energy and

93% less water while being equally effective.

Paper usage

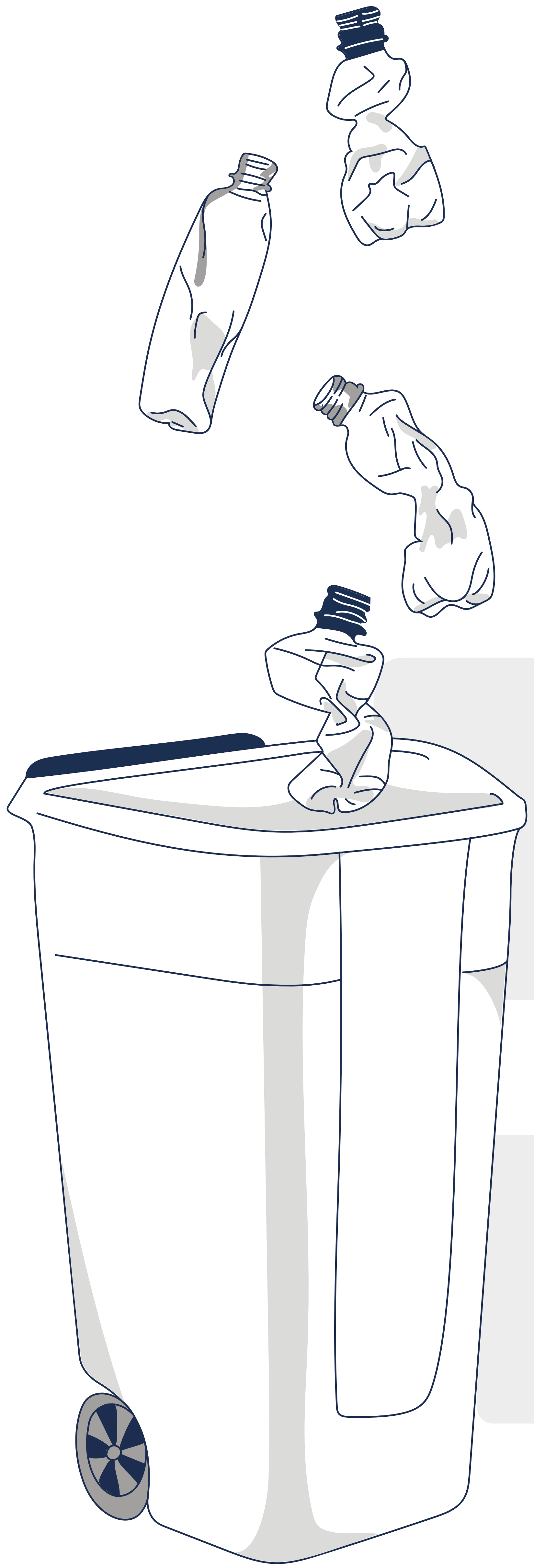
Even something as simple as a paper laboratory notebook may have a surprising environmental impact.

The **resources** required to manufacture one 150-page A4 laboratory notebook include **2.24 kg of wood, 9.73 kWh of electricity, 37.68 L of water, and 0.72 kg of CO_2 emissions**[14].



WASTE PRODUCTION

It has been estimated that research laboratories generate 5.5 million tons of plastic waste per year, equaling the combined tonnage of 67 cruise liners[2]. This equates to 2% of all annually generated plastic waste, although researchers take up a very small percentage of the total population[15]. Besides plastic waste, laboratories also produce landfill, recycling, compost, chemical, and biohazard waste. Particularly, biological and chemical hazards are energy intensive to process, because they must be sterilized and decontaminated before disposal[16].



Research Laboratory
Plastic Waste Generation =
5.5 million tons per year (2015)
(combined tonnage of 67 cruise liners)

Therefore, research laboratories contribute **2% of all plastic waste generation annually**

CONFERENCE TRAVEL

Many scientists travel frequently to attend conferences and collaborate internationally. While conferences are key for scientific discourse and communication, and collaborations are of high value to foster a diverse and international environment, long-distance air travel also is a large contributor to a scientist's carbon footprint. To approximate the magnitude of the scientific community's travel-related carbon emissions, Jeremany Nathans and Peter Sterling calculated the carbon emissions produced by the annual meeting of the Society for Neuroscience.

By calculating the mean round-trip distance traveled per person for each of the 30,000 attendees, Nathans and Sterling estimated that travel associated with a single scientific conference equates to 22,000 metric tons of CO_2 emissions[17].

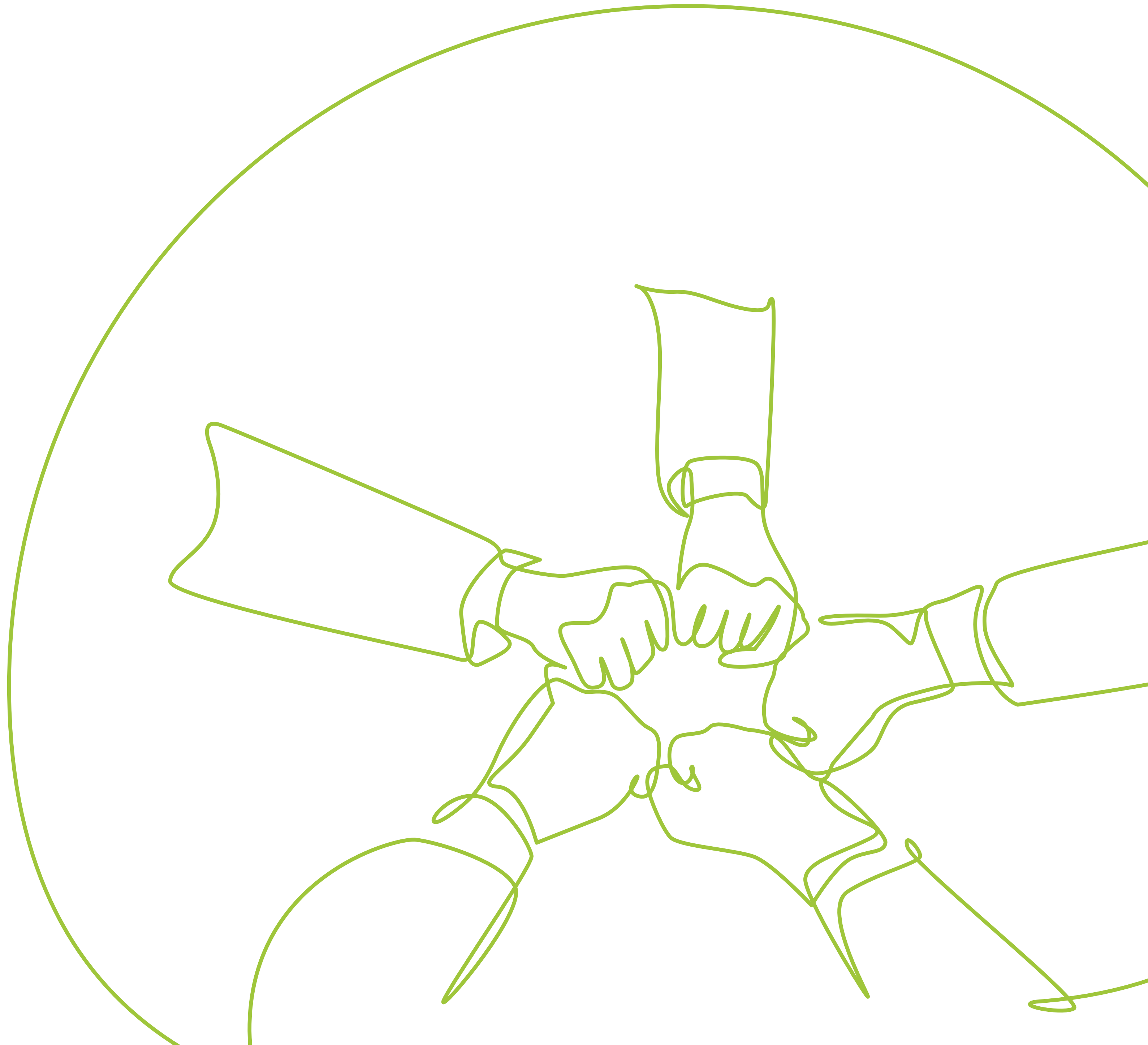
With the onset of the COVID-19 pandemic, many scientific communities turned towards live online alternatives for conferences and seminar series. While many have enjoyed the return of large, face-to-face international meetings, online alternatives, and small local meetings are undoubtedly the more ecologically feasible option. Nathans and Sterling suggest a judicious approach: scientists cut back to one large international meeting every two years (as opposed to annual conferences), which would already effectively prevent 22,000 metric tons of carbon emissions[17].

SOCIAL SUSTAINABILITY

Social sustainability, though often overlooked as a dimension of sustainability, is an important aspect to address to create healthy, ethical, diverse working environments[18]. Scientific disciplines, which have somewhat of a reputation for overworking, can experience particular challenges in creating positive and supportive work environments. For example, in a mental health assessment jointly conducted by Ghent University and Belgium's Scientific Institute of Public Health on Ph.D. students, they showed that approximately one-third of more than 3,600 doctoral students were at risk of developing mental health problems, especially depression, as measured by displaying four or more of 12 clinical symptoms[19].
Additionally, scientists are commonly taught that "*working longer means working better*", and therefore are particularly prone to over-working. Healthy work habits are key to fighting burnout, which can easily arise in research careers that require long hours and intense concentration for weeks or months on end[20]. Overall, increasing social sustainability measures at an institutional level may be a key step toward creating a more positive reputation and work environment.

In a laboratory or research environment, social sustainability includes the following measures:

- Quality of life measures such as physical and mental health, workplace safety, education, training, and skill development.
- Diversity measures such as the incorporation of a broad variety of viewpoints, beliefs, and values from a variety of cultural, ethnic, and experiential backgrounds.
- Measures of equity such as proactively identifying and minimizing disadvantages, promoting financial stability, and eliminating bias.
- Measures of social cohesion such as community development, public engagement, and fostering a sense of belonging[21].



BARRIERS SURROUNDING LABORATORY SUSTAINABILITY & HOW TO OVERCOME THEM

For the following sections we've interviewed sustainability experts on the challenges surrounding laboratory sustainability and how best to overcome them. We share insight from:

Dr. Kerstin Hermuth-Kleinschmidt
Founder of NIUB Nachhaltigkeitsberatung: Laboratory Sustainability Consultant

Matthias Schuh
CEO/ Co-Founder at Essentim: Laboratory Sensing & Monitoring Technology Provider

Franziska Clauß
Brand & Sustainability Communications Lead at Labforward: Laboratory Digitalization Expertise & Software Provider

AWARENESS

Challenge

One of the barriers Kerstin encounters in her work is a lack of awareness surrounding laboratory sustainability. When asked about awareness of sustainability in the lab, she recalled *"During a workshop where we discussed energy consumption of laboratory instruments, someone commented 'Oh! We have a cell culture incubator that we're not using at the moment. After this workshop, I will go shut it down.' I hear these types of remarks frequently, which suggests many researchers are not fully aware of their energy consumption, and even fewer are measuring or tracking it."*
She also admitted *"When I first started my business, back in 2014, I was shocked to realize figures such as 'one -80°C freezer uses as much energy as a single-family home'. I had no idea about any of these figures when I was a researcher."* Regarding cold storage energy consumption, Franziska explained further details laboratory users are commonly unaware of: *"For example, if you don't defrost your freezers or regularly sort out your old samples, both of these cause more energy consumption."*

Needless to say, this lack of awareness does not arise from a place of ignorance, but rather the opposite. Matthias comments *"Researchers are largely perceptive and well-educated people. The problem, then, is not exactly a lack of awareness, but rather that researchers may not be able to focus on these aspects because they are so busy with the amount of laboratory work that has to be done, most of which is still quite manual."*

Solution

Towards increasing awareness of laboratory sustainability issues, Kerstin is hopeful. She states *"Overall, awareness has been rising. People are thinking about how they can change their ways of working towards more sustainable practices. However, it may be necessary for some people to be more aware than others. For example, those with decision-making power, such as upper management, sustainability management departments, IT, as well as PIs, must be aware in order to delegate money and resources accordingly. At the same time, everyone involved should be aware and should have the opportunity to contribute ideas."* Much of Kerstin's job as a sustainability expert helps to increase awareness by holding workshops, webinars, conferences, and lectures, as well as publishing laboratory sustainability articles. You can find links to Kerstin's work in the Resources section of this whitepaper.

From the technology provider perspective, Matthias shares that his goal is to *"use technology to help scientists accelerate and automate their workflows. Not only does this increase a laboratory's reproducibility, but it also increases oversight of their processes, increases awareness by providing monitoring and power consumption data, helps them become more sustainable by saving resources and repeating experiments less often, and, importantly, frees up valuable time."*
From a communications perspective, Franziska added *"One of the main aspects of my job is raising awareness. Scientists, especially, have a huge amount of information to process at any given time. So if I can help visualize sustainability-related data better, this also helps inform a larger audience."*
Certainly, receiving information in an organized, reliable, and visually appealing format helps us digest it easier, which enables us to act on it.

For this purpose, we've created a sustainability content series, in particular, sustainability "*Quick Tips*" which you can find at the beginning of this whitepaper.

Chances are, if you're reading this whitepaper, you've already taken a huge step towards increasing your awareness!

INCENTIVES

Challenge

Matthias again acknowledges “*not everyone feels ‘able’ to care about sustainability if they have many other aspects preoccupying their attention. A researcher’s focus is on their research or in pharmaceutical companies, for example, their focus is on the success and safety of a product*.” In other words, scientists’ main incentive is their work. They often receive pressure from their institute to progress with their research, bring in funding, and publish papers in high-impact academic journals (i.e. the “*publish or perish*“ aphorism). Additionally, a laboratory is, by nature, a highly regulated, controlled environment, which is not always receptive to change. All in all, even if laboratory staff prioritize and make changes in their private life to live more sustainably, they may have trouble bringing this into their workplace.

Solution

To combat this, companies and research institutes alike must incentivize their employees to change to more environmentally friendly ways of working. Freie Universität (FU) Berlin, for example, have well-established sustainability incentives where other organizations could follow suit: In 2007, FU introduced a sustainability “*Bonus Scheme*” to provide a financial incentive for their departments to save energy. By using this system, a department receives an additional payment, equal to 50% of the money saved on energy consumption, if its energy consumption falls below a set threshold. On the other hand, if the department’s energy consumption exceeds this threshold, they must use their own departmental budget to pay the additional costs. Not only have nearly all departments at FU reduced their energy consumption and received annual payments since the launch of the system, but the university itself was able to cut energy costs by almost 28% (or by ~45 million kWh). The highest bonus to date, 270,000€ , was given to FU’s department of Biology, Chemistry, and Pharmacy.

Kerstin adds that money is not the only worthwhile incentive. She explains “*Scientists are focusing on their research. They need extra time to test out and establish more sustainable solutions. Currently, there are a lot of enthusiastic people implementing eco-friendly initiatives in their ‘free time’. If institutions were to acknowledge this and encourage setting aside time for this purpose, more researchers will feel comfortable doing so and those who were already doing it, would feel rewarded knowing that their efforts will be carried forward in the long term. Lastly, positive reinforcement goes a long way. People enjoy celebrating the results of their efforts.*”

ACCOUNTABILITY

Challenge

Considering that Ph.D. students (with contracts lasting approximately 4 years) and post-doctoral researchers (with contracts lasting approximately 3 years) are the work-horses of the academic world, there is high turnover in academic institutions. As a result, even if there is an enthusiastic, knowledgeable person willing to implement sustainability measures in the lab, if that person graduates or finds a new position, their efforts may be lost, preventing the adoption of sustainable practices in the long term and thwarting substantive change. Instead, these initiatives are best led by a dedicated sustainability project manager, though these positions are only beginning to be formally introduced.

On the topic of accountability, Franziska adds *„What is challenging is that, especially in the area of sustainability, one cannot necessarily see the positive effects immediately. In this way, sustainable aspects are also more long-term aspects. This can be difficult to grapple with when financial departments, for example, demand reportable figures*." In other words, it's too easy for companies and individuals to prioritize short-term benefits or convenience, over the long-term environmental benefits of investing in sustainability measures.

Solution

Perhaps the best way to hold individuals accountable for implementing sustainability measures, is to institutionalize these initiatives. This way, it is not up to an individual to enforce and advocate, but rather sustainability becomes shared and prioritized as a common value. Of course, still having an individual or small team who can serve as a source of knowledge and organization, can help to enforce, evaluate, and re-evaluate eco-friendly practices, Government initiatives to hold companies accountable, such as the European Union's Corporate Sustainability Reporting Directive (CSRD), are also gaining traction. This initiative, published on the 5th of January 2023 and affecting nearly 50,000 companies, now requires companies to publish reports measuring their sustainability performance[22]. These reports will inform funding and stakeholder decisions, driving the market more towards sustainable products and practices.

LEVELS OF COMMITMENT

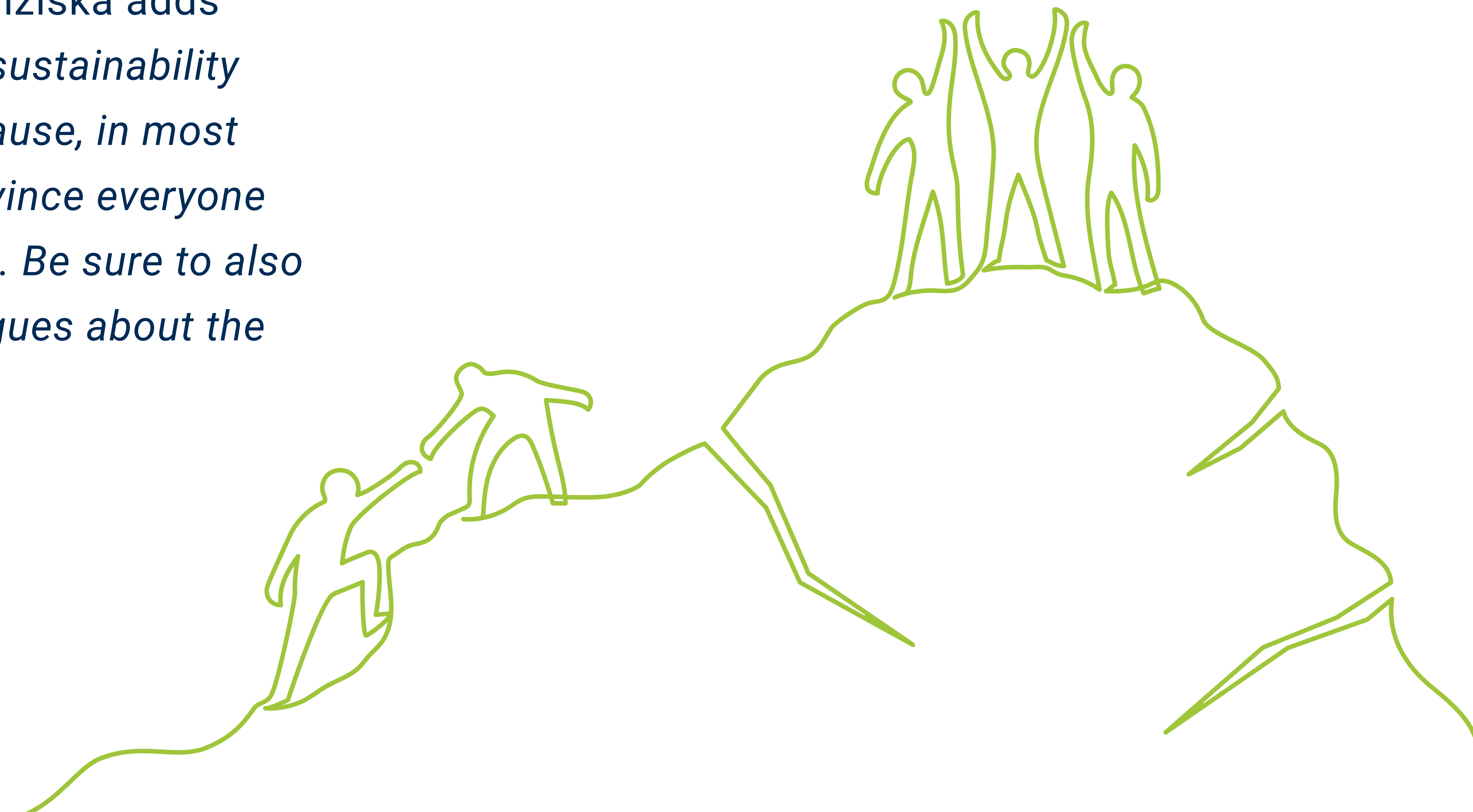
Challenge

Another challenge in the journey of becoming sustainable is differing levels of commitment between individuals. Franziska elaborates, *"There are people who do and don't want to implement changes at every level. There is a continuum of commitment, ranging from those who are extremely dedicated sustainability advocates, to those who are open to change but would not take action alone to, finally, those who are skeptical and express doubts."*

Solution

To get everyone on board Franziska suggests: *"When you want to implement changes, you have to include all organizational levels and be deliberate in simultaneously implementing change management. It is best to invite everyone and communicate transparently so that no one feels they are being forced into change. Different people have different needs and expectations and contribute different experiences and perspectives. People should be given a platform to talk about their concerns. These can feel like large changes; not only do they have to change their way of thinking but also how they work."*

Tying back in with the various dimensions of laboratory sustainability, Franziska adds *"Additionally, all dimensions of sustainability need to be considered also because, in most cases, you are not going to convince everyone just with the ecological benefits. Be sure to also inform yourself and your colleagues about the financial and social benefits."*



BENEFITS & DRAWBACKS OF BECOMING SUSTAINABLE

BENEFITS

Ecological

Some of the ecological benefits gained from introducing laboratory sustainability measures have already been discussed. For example, in regard to conference travel, if a research community were to change their annual conference to occur every other year instead, this would effectively prevent 22,000 metric tons of CO_2 emissions[17]. In the case of FU Berlin, which has very well-established and institutionalized sustainability programs, they have reduced their university's CO_2 emissions by 88.5% in 2021 in comparison to the program's inception in 2001[23]. In a plastic waste production case report conducted by the University of Edinburgh School of Medicine and Veterinary Medicine, a single microbiology lab of 7 researchers was able to reduce their plastic waste by about 43 kg per month. If all laboratories in their 200-person institute were to adopt similar waste reduction measures, up to 17,000 kg of biohazard waste could be prevented[24]. As seen through these examples, the ecological benefits scale greatly when sustainability measures are institutionalized. The purpose of a laboratory is already noble – to advance knowledge and make life-saving discoveries – but with reduced environmental impact comes an even greater sense of accomplishment and purpose.

Financial

Laboratories that have introduced sustainability measures have also reaped substantial financial benefits. For example, by replacing its autoclaves with more energy- and water-efficient models, the University of California Riverside saved 25,000 kWh of energy per year, equalling a minimum of $2,500/ year[12]. Scaled over the university's 37 autoclaves, this equals ~$92,500 worth of energy savings per year, just by replacing autoclaves. Even more impressive, FU Berlin avoided 6.1 million Euros in energy costs in 2021 due to the excellent implementation of their sustainability initiatives. Overall, since FU started its sustainability initiatives in 2000, they estimate total avoided energy costs of 64.5 million Euros. In addition to avoided energy costs, FU also saved 459,000€ on the cost of water and 67,000€ on the cost of waste disposal in 2021, compared to their baseline measurements in 2004. FU also reduced its paper consumption from 151 tons in 2015, to 39 tons in 2021, equivalent to a savings of about 112,000€ [23].

Even a comparatively small-scale change can have a large financial impact. For example, when a group of 7 microbiology researchers at the University of Edinburgh transitioned from plastic inoculation loops to metal inoculation loops they saved 225£ per year. Reusing 15 and 50mL Falcon tubes saved the researchers 1,390£ per year[24]. If the entire institute were to take similar action, approximately 45,000£ could be saved per year just by replacing or reusing 2 single-use plastic items. Furthermore, the financial benefits associated with introducing sustainability measures are particularly timely. With present-day concerns over the cost of energy and energy market volatility, many research institutes have implemented cost-saving measures and measures to substantially reduce the energy consumption of their buildings[25,26].

Social

There are also a variety of social benefits to be gained upon introducing or increasing sustainability initiatives – particularly if social sustainability measures are included. One such benefit is increased workplace safety, such as lower exposure to biochemical hazards which can be achieved by better inventory oversight, proper safety training, and process automation. Another social benefit, achieved by digitalizing workflows, preventing unnecessary experimental repetitions, and respecting working hours is lowering the risk of burn-out and mental and physical health problems. Along with improved mental and physical health comes increased productivity and motivation, higher internal morale, and better employee engagement. A socially sustainable laboratory also promotes a diverse working environment which increases creativity and provides a variety of perspectives needed to tackle complex scientific questions. Lastly, scientists play a vital role in the community's perception of and trust in science. Improving the company-community relationship by communicating transparently, advocating science, and involving the community in educational activities can have positive effects such as inspiring the next generation of scientists, increased funding, and favorable policy and political decisions.

Benefits Summary:

To summarize, Kerstin explains that many of these benefits are manifold: *"For example, take a single measure such as changing from a paper to a digital laboratory notebook. Switching to a digital solution often streamlines documentation efforts, making it easier to share experiments* *and results, even negative ones. Doing so, saves resources by avoiding the repetition of experiments, simplifies sharing best practices on how to do specific experiments, and saves researchers time, ultimately improving their working environment. After all, this decision also reduces the laboratory's environmental impact by saving paper and money on printer cartridges, and reduces the number of required deliveries which saves money and reduces carbon emissions."*

DRAWBACKS

Despite the myriad of positive benefits associated with improving laboratory sustainability, laboratory users may also experience some drawbacks along the way. One potential drawback is that introducing sustainability measures may require additional time investment and organizational effort. For example, in the case report by the University of Edinburgh, they found the introduction of metal inoculation loops, while more ecologically friendly, more time-consuming to use than plastic loops because metal loops must be decontaminated by a flame and cooled between uses. Their decontamination process, necessary to be able to reuse plastic consumables, also introduced more responsibilities for researchers and for service teams (by about 30 min per week).
Another drawback they experienced was that not all consumables had a suitable sustainable alternative or that some substitutes were unsuitable for their research needs. Glass culture tubes, for example, are not appropriate for centrifugation and reusable glass Petri dishes are not appropriate for performing tissue culture procedures that require nonpyrogenic and non-cytotoxic materials[24]. Additionally, implementing sustainable solutions may mean incurring additional upfront costs, particularly before cost-saving measures are able to accumulate. For example, the process of replacing the University of California Riverside's autoclaves with more energy-efficient models required about $1.48 million in upfront costs. While money saved on energy and water allowed these autoclaves to "pay for themselves" over time, organizations may need to carefully consider their sustainability budget, and which solutions they will benefit from the most.

In summary, it is important to communicate clearly about potential roadblocks and negative aspects. Being honest, aware, and transparent is vital to make sure expectations are reasonable and will assist in implementing the change management process. Overall, there may be a substantial learning curve in each laboratory's sustainability journey, but importantly laboratories do not have to face these challenges alone.

OUR SUSTAINABILITY PARTNERSHIP

Due to our shared interests in laboratory sustainability, Matthias, Kerstin, and Labforward have partnered together to offer a comprehensive, customizable, digital laboratory sustainability solution. Matthias' company, essentim, provides IoT-Monitoring Systems and sensor technology that help laboratories reduce errors and increase reproducibility, thus reducing resource usage. Kerstin's company, NIUB Nachhaltigkeitsberatung, offers sustainability consulting services to life sciences industries. Our shared solution devises a custom action plan for laboratories, depending on their sustainability goals and operational requirements, and includes collecting energy consumption data and crafting a report outlining the laboratory's progress.

In a current pilot project testing our approach, essentim sensors were installed on freezers, fridges, cell culture incubators, and autoclaves, to collect baseline energy usage measurements. Data is being continuously transferred to, analyzed by, and displayed on the Laboperator dashboard (see Section 8 to learn more about Laboperator). Next, Kerstin will utilize the insights gathered from the sensor data to carry out her ecomapping™ method and workshop, helping the lab come up with an action plan[27]. After sustainability measures are implemented, another sensor data collection period will be conducted by essentim and Labforward to measure the lab's progress. A follow-up meeting with Kerstin also takes place 3-6 months after implementation to monitor progress and to refine the measures if necessary. Lastly, a report outlining sustainability improvements will be provided to the customer for both internal documentation and external presentation.

Overall, our partnership is an exciting and promising opportunity to help laboratories save resources, reduce their carbon footprint, and become more sustainable. With our combined expertise and experience, we aim to provide high-quality guidance to support and optimize laboratory operations to be highly performant and more environmentally friendly.

LABFORWARD'S STANDPOINT

At Labforward, we are committed to using technology and digitalization to help laboratories become more sustainable. We believe digitalization serves as a vital tool to provide laboratory users with better oversight over their inventory, protocols, data, and documentation. This increased oversight frees up valuable time and resources, provides scientists with device monitoring necessary to make data-driven decisions, and helps prevent human-error, material waste, and unnecessary experimental repetition. Despite these benefits, we also recognize that introducing technological solutions often generates more data, which, as previously discussed, requires computational power to analyze and energy to store on servers. On this topic, our CEO, Dr. Simon Bungers adds *"Digital solutions can help scientists make their laboratory practices more sustainable, but it has to be applied responsibly."* Therefore, we aim to implement our technological solutions in an informed and well-thought-out manner and insure that our products are designed with both the researcher and the environment in mind:

Labfolder: Electronic Lab Notebook (ELN)
Switching an ELN can have a variety of beneficial ecological impacts. For example, Labfolder users save resources and storage space by eliminating traditional paper lab notebooks and pen-and-paper protocols. Additionally, historical data can be easily accessed which saves time and prevents unnecessary resource usage. Additionally, ELNs can help to reduce a laboratory's carbon footprint by facilitating digital collaboration among teams, both internally and worldwide.

Labregister: Inventory Management System
Implementing an inventory management system such as Labregister provides laboratory users with an up-to-date overview of their inventory and allows them to view the amount, location,

and expiry dates of reagents, samples, and consumables. This helps lab managers to stay on top of ordering, avoid duplicate orders, preorder heavily used items in bulk advance shipments, and overall prevent excess CO_2 emissions.

Laboperator: Laboratory Execution System (LES)
A laboratory execution system, used for continuous device monitoring and protocol automation, can help to reduce health and safety risks, and prevent human error and resource waste. Additionally, we have also created specific workflows catered toward sustainability.

For example, cold storage monitoring ensures optimal heat exchange in a laboratory's cold storage devices and reminds users to regularly perform maintenance tasks (defrosting and vacuuming freezer coils) via customizable notifications. Additionally, Laboperator can be configured to automatically shut down equipment such as water baths, tissue culture hoods, lights, etc. when not in use. Overall, while laboratory execution systems, such as Laboperator, are relatively recently developed in comparison to ELNs and inventory management systems, they hold huge potential in helping laboratories become more sustainable in their everyday operations.

Conclusion
Overall, we are hopeful for the future of sustainability in the laboratory and are committed to producing accessible and user-friendly products to assist in the sustainability journey. To conclude, Simon comments:

"As scientists, we have a responsibility to protect the environment, stay involved, be aware, and change our ways of working accordingly. Luckily, one can never underestimate the creativity of researchers. We are coming up with creative ways to become more sustainable together."

REFERENCES & RECOURSES

References

1. Business Energy Advisor - Business types - Laboratories. (2021) https://esource.bizenergyadvisor.com/categories/business-types.
2. Urbina, M. A., Watts, A. J. R. & Reardon, E. E. Labs should cut plastic waste too. Nature 528, 479–479 (2015). DOI: 10.1038/528479c
3. Paradise, A., Market Assessment of Energy Efficiency Opportunities in Laboratories. 169. (2015) www.etcc-ca.com/sites/default/files/reports/ceel_market_assessment_et-14pge7591.pdf
4. U.S. Energy Information Administration (EIA). (2021) https://www.eia.gov/tools/faqs/faq.php?id=96&t=3
5. Jones, N. How to stop data centres from gobbling up the world's electricity. Nature 561, 163–166 (2018). DOI: 10.1038/d41586-018-06610-y
6. Grealey, J. et al. The Carbon Footprint of Bioinformatics. Mol. Biol. Evol. 39 (2022). DOI: 10.1093/molbev/msac034
7. Lannelongue, L., Grealey, J. & Inouye, M. Green Algorithms: Quantifying the Carbon Footprint of Computation. Adv. Sci. 8, 2100707 (2021). DOI: 10.1002/advs.202100707
8. Tanner S. et al. Laboratories for the 21st Century - U.S. Environmental Protection Agency. Water Efficiency Guide for Laboratories. (2005) DOE: GO-102005-2008
9. National Institutes of Health. Laboratory Water. (2013) https://orf.od.nih.gov/TechnicalResources/Documents/DTR%20White%20Papers/Laboratory%20Water-Its%20Importance%20and%20Application-March-2013_508.pdf
10. Tanner, S. et al. International Institute for Sustainable Laboratories. Best Practices Guide: Water Efficiency in Laboratories. (2022) https://www.i2sl.org/documents/I2SLBestPractices_WaterEfficiencyinLaboratories_June2022_v2.pdf
11. Merk Millipore. Comparison of the environmental impact of an Elix® 3 water purification system. (2014) https://www.sigmaaldrich.com/deepweb/assets/sigmaaldrich/product/documents/329/254/comparison-of-the-environmental-impact-mk.pdf
12. Faugeroux, D., Wells, B., LaboratoryDesign 20-6,(2016) https://www.priorclave.com/en-us/wp-content/uploads/sites/3/2018/08/LabDesign_Dec2016.pdf
13. Davis, C. Equipment retrofit reduces water use in campus labs. Sustainability (2014) https://sustainability.ncsu.edu/blog/2014/09/03/equipment-retrofit-reduces-water-use-in-campus-labs/.
14. Nachhaltigkeitsrechner. Papiernetz https://www.papiernetz.de/informationen/nachhaltigkeitsrechner/
15. Ritchie, H., Roser. M. "Plastic Pollution". OurWorldInData.org. (2018) ‚https://ourworldindata.org/plastic-pollution'
16. Leak, L. B., Tamborski, J., Commissaris, A. & Brophy, J. A. N. Forging a path toward a more sustainable laboratory. Trends Biochem. Sci. 48, 5–8 (2023). DOI: 10.1016/j.tibs.2022.09.001
17. Nathans, J. & Sterling, P. How scientists can reduce their carbon footprint. eLife 5, e15928. DOI: 10.7554/eLife.15928
18. Ajmal, M. M., Khan, M., Hussain, M. & Helo, P. Conceptualizing and incorporating social sustainability in the business world. Int. J. Sustain. Dev. World Ecol. 25, 327–339 (2018). DOI: 10.1080/13504509.2017.1408714
19. Levecque, K., Anseel, F., De Beuckelaer, A., Van der Heyden, J. & Gisle, L. Work organization and mental health problems in PhD students. Res. Policy 46, 868–879 (2017). DOI: 10.1016/j.respol.2017.02.008
20. Powell, K. Work–life balance: Break or burn out. Nature 545, 375–377 (2017). DOI: 10.1038/nj7654-375a
21. ADEC Innovations, What is social sustainability? https://www.adecesg.com/resources/faq/what-is-social-sustainability/.
22. Directorate-General for Financial Stability, Financial Services and Capital Markets Union. Corporate sustainability reporting. European Comission. (2023) https://finance.ec.europa.eu/capital-markets-union-and-financial-markets/company-reporting-and-auditing/company-reporting/corporate-sustainability-reporting_en.
23. Wanke, A., Tacke, B., Große, N., Taige,l J., Schweigel, K., Sustainability and Energy Management Unit - Freie Universität Berlin. (2022) https://www.fu-berlin.de/sites/

nachhaltigkeit/stabsstelle/kommunikation/berichte/_inhaltselemente/NB_englisch_2022.pdf.

24. Alves, J. et al. A case report: insights into reducing plastic waste in a microbiology laboratory. Access Microbiol. 3, 000173 (2021).
25. Press and Public Relations Office of the Deutsche Forschungsgemeinschaft. Science and research in the energy crisis. (2022) https://www.humboldt-foundation.de/en/explore/newsroom/press-releases/science-and-research-in-the-energy-crisis
26. Popkostova, Y. European Union Institute for Security Studies. Europe's energy crisis conundrum. (2022) https://www.iss.europa.eu/content/europes-energy-crisis-conundrum.
27. Hermuth-Kleinschmidt, Kerstin. Ecomapping™ – An easy way to make your lab work more sustainable. https://niub-nachhaltigkeitsberatung.de/en/2022/06/13/ecomapping-an-easy-way-to-make-your-lab-work-more-sustainable/

Additional Resources

Kimberly-Clark Professional - The RightCycle™ Program https://www.kcprofessional.de/de-de/solutions/rightcycle-by-kimberly-clark-professional

Dr. Kerstin Hermuth-Kleinschmidt - NIUB Nachhaltigkeitsberatung - Sustainability Consulting for Life Sciences. https://niub-nachhaltigkeitsberatung.de/en/

Labconscious is an open resource and blog for the life science community to reduce laboratory waste, use green chemistry, conserve water and save energy. https://www.labconscious.com/

Nikoline Borgermann & Adriana Wolf Perez's The Caring Scientist: Mission Sustainable | Podcast on Spotify. https://open.spotify.com/show/1BCQF97RRT8YcBCPMjCvVM

My Green Lab is non-profit organization committed to improving the sustainability of scientific research. https://www.mygreenlab.org/

The International Institute for Sustainable Laboratories (I2SL) is a non-profit organization focused on education to ensure safe, sustainable laboratory design, operation, and use. https://www.i2sl.org/index.html

The Freezer Challenge, jointly run by My Green Lab and the International Institute for Sustainable Laboratories, is a competition designed to promote best practices in cold storage management. https://www.freezerchallenge.org/

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