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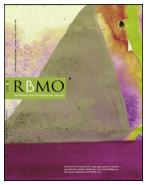
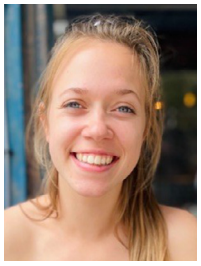


REVIEW

Sustainability in the IVF laboratory: recommendations of an expert panel



BIOGRAPHY

Francesca Farlie is a Trainee Embryologist at Concept Fertility, London, UK. Beyond embryology, she has a passion for the environment and has made a commitment to help reduce the carbon footprint of assisted reproductive technology. She is working toward the green transformation of her own workplace while encouraging others to do the same.

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KEY MESSAGE

Assisted reproductive technology has a significant carbon footprint via laboratory and clinical operations. The authors offer some practical steps that can be taken by practitioners towards achieving sustainability in IVF laboratories. These actions are incumbent on all of us if we are committed to 'first do no harm.'

ABSTRACT

The healthcare industry is a major contributor to greenhouse gas emissions. Assisted reproductive technology is part of the larger healthcare sector, with its own heavy carbon footprint. The social, economic and environmental costs of this collective carbon footprint are becoming clearer, as is the impact on human reproductive health. Alpha Scientists in Reproductive Medicine and the International IVF Initiative collaborated to seek and formulate practical recommendations for sustainability in IVF laboratories. An international panel of experts, enthusiasts and professionals in reproductive medicine, environmental

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KEY WORDS

Carbon footprint
Climate change
Green certification
IVF sustainability
Life-cycle analysis
Waste management

science, architecture, biorepository and law convened to discuss the topics of importance to sustainability. Recommendations were issued on how to build a culture of sustainability in the workplace, implement green design and building, use life cycle analysis to determine the environmental impact, manage cryostorage more sustainably, and understand and manage laboratory waste with prevention as a primary goal. The panel explored whether the industry supporting IVF is sustainable. An example is provided to illustrate the application of green principles to an IVF laboratory through a certification programme. The UK legislative landscape surrounding sustainability is also discussed and a few recommendations on 'Green Conferencing' are offered.

INTRODUCTION

First do no harm

The global climate is changing due to human activity and greenhouse gas (GHG) emissions (*Intergovernmental Panel on Climate Change [IPCC], 2023*). These changes have serious social, economic, environmental, ecological and human health consequences.

Ironically, the healthcare sector is a major contributor to GHG emissions and the associated adverse health effects. The data are startling: according to an extensive study published by the international non-governmental organization Healthcare Without Harm, the carbon footprint of the sector is 4.4% of global net emissions, with the USA, China and the European Union (EU) being the three top emitters. The report further identifies the US health sector as 'the world's number one emitter in both absolute and per capita terms' (*Healthcare Without Harm, 2019*).

Assisted reproductive technology (ART), as a specialty within the larger healthcare sector, has its own environmental impact, via laboratory and clinical operations. IVF laboratories are now being built as highly specialized spaces with sophisticated and energy-intense air handling systems. They house and operate other equipment that consumes significant amounts of energy and is often left running continuously. Human gamete and embryo culture is performed in plastic dishes, and virtually all other protocols require the use of disposable, single-use plastics that come heavily packaged to protect their integrity and sterility. Many IVF laboratories still generate paper records and paper waste. Large quantities of specialty gases are required for the operation of incubators, and liquid nitrogen (LN2) is necessary for the cryopreservation and cryostorage of gametes, embryos and reproductive tissues. Transportation of these cylinders and tanks is entirely fossil fuel dependent, creating a significant environmental burden. The transport of cryopreserved reproductive cells and tissues across cities, countries and continents has become routine, with enormous environmental implications.

Environmental degradation via human activity impacts reproductive health, including fertility, pregnancy and fetal development, which can reach across multiple generations (*Segal and Giudice, 2022*). The ubiquitous use of plastics is one aspect of great concern. Plastics and microplastics, the product of their breakdown, are environmental pollutants that are overwhelming landfills and oceans. Microplastics can enter the body through inhalation, ingestion and skin contact and threaten human fertility through their endocrine-disrupting properties (*Segal and Giudice, 2022*). They were recently detected in human placental tissue (*Ragusa et al., 2021*), requiring further investigation of a possible association with adverse birth and developmental outcomes (*Medley et al., 2023*).

The clinical side of IVF is also carbon-footprint heavy. From single-use stainless steel oocyte retrieval needles (with their attached Teflon tubing and silicon stopper with syringe connection) and embryo transfer catheters to the heavy use of disposable personal protective equipment, multi-day monitoring of hormones via clinical laboratory testing, and daily injections delegated to the patient under treatment, each treatment cycle is energy intense and creates large quantities of waste.

Awareness of these issues has now reached a critical level, providing an opportunity for a collective response and action. Several health systems around the world are already undertaking efforts towards decarbonization and sustainability (*Healthcare Without Harm, 2019*). The ART community must join this effort. Incorporation of an 'environmental management system' (e.g., ISO 14001) into the larger quality management system for the laboratory and validation of the system through certification would be an important step towards achieving a goal of sustainability. Thus, all stakeholders should be sensitized to the importance of adopting sustainable environmental practices, and those in a management position should support these efforts, understanding that the initial costs are a price for future savings (*Lopez et al., 2017*). As teamwork is at the heart of delivering optimal care in the IVF laboratory (*Campbell et al., 2022*), it should also be a central principle if sustainability efforts are to succeed.

Alpha Scientists in Reproductive Medicine (Alpha Scientists) and the International IVF Initiative (I3) have a common primary mission to educate and inform scientists in reproductive medicine and those practising in ART. We also envision our collaborative efforts leading to meaningful and positive change and progress in the field. Concerned about the impact of the field's work on the health of the environment and people (including patients), we invited an international group of professionals in reproductive medicine, environmental science, architecture and law to formulate recommendations for 'Green IVF®'.

The experts and panellists met for two 4-hour online sessions — a green conferencing format — during which they presented and discussed various topics of importance to sustainability. Each presenter also submitted a written extended abstract of their talk, complete with references. This collection was then collated into one document, edited, distributed to the full panel of participants for input, and finalized for submission after approval by each member of this working group. The paper is thus divided into sections authored by each presenter. This is followed by recommendations and practical steps that IVF laboratory practitioners can take in order to move toward sustainability, fulfilling our obligation to society and ensuring a better future for the patients we treat, the lives we help create and the next generations of ART practitioners. A glossary of terms (**TABLE 1**) is provided to define terms commonly used in the area of sustainability.

TABLE 1 GLOSSARY OF TERMS

Term	Definition
ACT® label	Accountability, Consistency, and Transparency Label (My Green Lab)
Bioplastic	Plastics manufactured from bio-based polymers
Carbon footprint	Total greenhouse gas emissions released into the atmosphere as a result of human activity (individual, organization or community)
Carbon footprinting	Measurement of the carbon footprint calculated by adding the emissions resulting from every stage of a product or service's lifetime
Circular economy	Using products more efficiently and returning waste back to the economy
Decarbonization	Process of reducing the amount of carbon released into the atmosphere
Eutrophication	Excessive nutrients in a body of water, mainly due to run-off from farmland, causing a dense growth of plants and death of animals from lack of oxygen
Greenhouse gases	Seven gases are included: carbon dioxide, methane, hydrofluorocarbons, perfluorocarbons, sulfur hexafluoride, nitrous oxide and nitrous trifluoride
Greenwashing	Misleading or deceptive actions or claims made by an organization so as to appear more environmentally responsible
Net zero	Overall balance between the amount of GHG released and removed from the atmosphere
Paris Agreement	International treaty providing the framework to limit climate change and rising global temperatures
Plug load	Energy used by electrical equipment (wattage) while plugged into an electrical outlet
Scope 1 emissions	Direct GHG emissions from sources that are owned or controlled by an entity (e.g. emissions from manufacturing processes or on-site fuel combustion)
Scope 2 emissions	Indirect GHG emissions associated with the generation of the purchased electricity, heating and cooling consumed by an entity
Scope 3 emissions	Accounting for 40–80% of all emissions, includes upstream transportation, waste generated, business travel, employee commuting, downstream transportation and distribution

BUILDING A GLOBAL CULTURE OF SUSTAINABILITY IN SCIENCE

Pernilla Sörme

Historically, the ends have justified the means in clinical and research laboratory operations, the end being the curing of human maladies and the means being the allocation of all resources – material, human and financial – to achieve that goal. However, this premise is rapidly changing. Recent years have seen the emergence of a laboratory sustainability movement around the world (*Greever et al., 2020*). Championed by a coalition of organizations and individuals, the movement seeks to institutionalize sustainability in laboratories through the creation and adoption of new action plans and programmes.

Bringing sustainability into the laboratory environment is challenging. Laboratories are demanding spaces that require specialized buildings, equipment and personnel. Additionally, each laboratory is unique, with specialized protocols and its own culture, so sustainability solutions that work for one laboratory may not work for another. Sustainability programmes are most successful when their framework addresses laboratory functions holistically by encouraging scientists to reduce energy, waste, water and hazardous chemical use, and to be mindful when purchasing laboratory supplies (*Paradise, 2021*).

To create long-lasting sustainability, multiple aspects of laboratory operations that support a 'net zero' future should be considered. This transformation is envisioned 'as a process that takes place across three embedded and interacting spheres: practical, political, and personal' (*O'Brien and Sygna, 2013*). Perhaps the most powerful or all-encompassing of these spheres and a prerequisite to achieving sustainability goals is the 'personal', defined as the 'transformation of individual and collective beliefs, values and world-views' (*O'Brien and Sygna, 2013*). Behaviour change cannot be forced – it requires 'buy-in', and 'buy-in' requires engagement. Each member of a laboratory should feel responsible for an aspect of the laboratory sustainability effort and bring conviction to the effort. This in turn leads to a change in culture, which ensures the long-term success of the sustainability programme. Moreover, networking is important for sharing best practices and building the support structure for sustainable laboratory approaches. Research institutions around the world are experiencing first hand the many benefits of laboratory culture changes that support sustainability, among these the alignment of individual and institutional values and reduction in operational costs (*My Green Lab, 2021*).

Behaviour change can be achieved through top-down or bottom-up strategies. Top-down is when decision making comes from senior management and is communicated to the laboratory. Bottom-up is when an individual or laboratory begins the sustainability changes and builds a larger community of laboratories supporting sustainability; i.e. it is a grassroot movement. For behaviour change efforts to be truly successful both top-down and bottom-up strategies are needed (*Connelly, 2021*).

Change begins with awareness. Stakeholders, from individuals to groups to organizations, must become aware of the existence of the problem and recognize their own power to effect change before they can act. Bringing awareness of the massive environmental impact of science, while demonstrating to the laboratory community that there is a more sustainable way to conduct their work, is a far more effective approach than simply providing information. The next step is to assess the status of laboratory operations and aim to improve sustainability through the adoption of sustainability programmes and initiatives, while encouraging continuous engagement and

improvement. Finally, it is important to recognize, elevate and reward those who play a critical role in building a new culture in the organization and its permanent transformation. Participation in a certification programme such as those offered by ISO 14001 and My Green Lab, although not specific to IVF laboratories, is an effective means of starting and maintaining these efforts.

Importantly and fundamentally, all sustainability initiatives and strategies in laboratories must support and be in harmony with the aims of the larger organization. The top priority of scientists and clinicians is to provide the best care to patients and conduct impactful and responsible research. Hence, any laboratory sustainability movement should be flexible rather than prescriptive to allow for different options and alternatives that suit the specific activities of the laboratory.

Creating a sustainability culture in laboratories might seem like a daunting task but getting started is key. The first successful step will create confidence and encourage individuals and teams to reach for further achievements. Even seemingly small actions in the laboratory can have large sustainability impacts.

Recommendations

- Bring awareness and education to the laboratory about the environmental impact of laboratory work.
- Aim for enduring behaviour and mindset change.
- Form a 'green team' to explore ways in which the laboratory's carbon footprint can be reduced.
- Engage all members of the laboratory and organization, including facilities, safety and procurement, in sustainability efforts.
- Gain the support of management for the laboratory's sustainability efforts.
- When feasible, participate in a 'green certification' programme to achieve these goals.

HOW SUSTAINABLE IS THE INDUSTRY SUPPORTING IVF?

Anna Gorbunova

Many companies in the healthcare sector, including those that cater to IVF, publish annual sustainability reports such as an environmental, social and governance (ESG) report or corporate social responsibility (CSR) report, to communicate their strategies toward sustainability and actions to reduce their negative environmental impact. These reports can provide a measure of a company's commitment to sustainable operations. However, it is important to point out that, in some instances, companies (none that have been reviewed here) have been accused of 'greenwashing' and 'wildly inflated climate claims' (*Elgin and Rangarajan, 2022*). Unfortunately, a sustainability rating system for suppliers does not currently exist. However, such a system could conceivably be developed to enable informed decisions on purchasing as well as to encourage companies to expand their sustainability efforts.

To assess the level of commitment to sustainability in the industry supporting IVF, publicly available sources such as company websites were examined for nine suppliers that serve IVF clinics around the world. These companies were Cryotec (Japan), Kitazato (Japan), Irvine Scientific (which belongs to *Fujifilm Holdings*

Company	Year of Report	Reporting Standards	Green House Gas Emission (GHGe) Reduction Plan	Waste Management Plan	Reported Renewable Energy Consumption	Reported Water Management	Sustainable Product Solutions	Recycling Initiatives
Cooper (CooperSurgical specifically when labeled with *)	2020 2021 2022	SASB	• Scope 1, 2, 3 monitored to set GHGe reduction plan	• Global waste reduction program under development • Focus on materials reduction, recycling, and reuse	• 100% at some facilities	• 35% consumption reduction at some facilities	• Reusable, recyclable and biodegradable cold-chain shipping boxes (*)	• Partnership with Plastic Bank
Vitrolife	2022	Swedish Annual Accounts Act	• Scope 1, 2, 3 monitored to set GHGe reduction plan	• Focus on waste reduction and optimization of waste recovery, recycling and reuse	Not found	Not found	• Bioplastics solutions under development • Reduction of packaging materials	• Recycling of internally used plastic, cardboard and polystyrene
ThermoFisher	2021	UN SDG SASB GRI TCFD	• Net Zero emissions by 2050 • 30% reduction in Scope 1 & 2 emissions compared to 2018 baseline by 2030 • 12% reduction in 2021	• 24 zero-waste-certified facilities • Waste reduction as a priority	• 22% globally • 100% at over 60 sites	• 13% consumption reduction compared to 2020	• Energy Star certification of equipment • ACT label • 'Greener Choice' product line • Recyclable paper cooler	• Single-use lab plastics recycled to manufacture plastic shipping pallets
Corning (Life Science branch specifically when labeled with **)	2022	SASB TCFD GRI UNSDG	• 30% reduction in Scope 1 & 2 emissions compared to 2021 baseline and 17.5% reduction for Scope 3 by 2028	• Over 80% waste diversion globally by 2028	• Plan for 400% increase compared to 2018 by 2030 • Commitment to 100% renewable energy in US and Europe by 2028	• Waste water recycling at some manufacturing facilities • Water use reduction	• Design improvement of some products (**) • Reloadable pipette tip boxes made of 100% recycled polypropylene (**)	• Development of recycling methods for single-use plastics (**)
Cook	Up to 2022	Not found	• Emissions reduction as a priority area in CSR	Not found	• Solar panels installed in Australian and US facilities	Not found	• Chemical modifications of products to exclude PVC and DEHP	• Nitrile gloves recycling
ESCO	2021 (?)	Not found	Not found	• Waste recycling project to make building bricks • Waste segregation	• Plan for lower power consumption and noise	• Monitoring of water consumption. • Rain water collection	Not found	Not found

FIGURE 1 A list of companies reviewed for their sustainability actions and policies. The figure summarizes the companies' reporting standards, emission reduction plans and product-related actions. the Information provided was obtained from the company's reports and website and, in some cases, by direct communication with the company. The claims have not been independently verified by the authors. * Cooper Surgical. ** Life Science branch of Corning. ACT® Label, Accountability, Consistency, and Transparency Label (My Green Lab initiative); CSR, corporate social responsibility; DEHP, di(2-ethylhexyl)phthalate, a phthalate and plasticizer; GHGe, green house gas emissions; GRI, global reporting initiatives; PVC, polyvinyl chloride, a synthetic polymer of plastic; SASB, Sustainable Accounting Standards Board; TCFD, Task Force on Climate-Related Financial Disclosures; UN SDG, United Nation's Sustainable Development Goals.

Corporation, Japan), ESCO (Singapore), Cook Medical (USA), Cooper Companies (USA), Thermo Fisher Scientific (USA), Corning (USA) and Vitrolife (Sweden) (**FIGURE 1**, Supplementary Figure).

Two companies (Cryotec and Kitazato) do not appear to publish sustainability information or provide annual reports, or at least such reports are not easily accessed. (https://www.cryotec.com, https://www.kitazato-ivf.com). Fujifilm's reported data are not discussed here because no specific information regarding the company's IVF supplier arm, Irvine Scientific, was provided.

ESCO Group has an ESG tab on its website containing information on a code of ethics, an environmental policy and a number of environmentally friendly operations, including the use of energy-efficient technologies (in particular in laminar flow hood design and construction) and training seminars for distributors (https://www.escolifesciences.com/about-us/environmental-social-and-corporate-governance). An ESG report could not be found on the ESCO website. Cook Medical provides a CSR report on its website) (https://csr.cookmedical.com)

Other companies published downloadable annual performance reports. The reports of five companies (*Cook Medical* (n.d.), *Vitrolife Group (2022)*, Cooper Companies (2020, 2021), *Thermo Fisher Scientific (2021)* and *Corning (2022)*) were further analysed on their ESG actions (see the links in the list of references).

There is currently no unified format for sustainability data reporting; subsequently, the type of information provided and the presentation style vary by company. For example, Cooper, Corning and Thermo Fisher Scientific disclosed reporting standards while Vitrolife followed national regulations for the preparation of financial statements set by the Swedish Annual Accounts Act (https://www.bfn.se/english/regulations). Most of the companies reviewed here are in the 'large corporations' category that provide general reports reflecting the performance of all the subsidiary companies.

To reduce their negative environmental impact, companies generally focus on energy efficiency, water consumption, waste management and product design.

Product design and packaging is of major interest for IVF and ART. Corning and Thermo Fisher Scientific have developed more environmentally friendly laboratory consumables with a lower plastic content to lower energy consumption during production.

Waste reduction is one of the central sustainability approaches of Thermo Fisher Scientific. According to its report, the company has 24 'zero-waste' facilities, where at least 90% of non-hazardous waste is diverted from landfills and into waste-to-energy facilities. For that, the manufacturer focuses on reuse, recycling and composting strategies.

With respect to materials, Vitrolife has announced the development of 'bioplastic.' Although it does not provide a definition of 'bioplastic' or comment on this in its report, according to (*Rosenboom et al. 2022*) the term 'bioplastic' typically refers to plastics manufactured from bio-based polymers, which may contribute to more sustainable commercial plastic life cycles.

Cook Medical has stopped using polyvinyl chloride in its products. Polyvinyl chloride is a synthetic polymer of plastic the manufacturing of which can release dioxins, phthalates and vinyl chloride into the air, posing risks to both human health and the environment. Cook is also exploring opportunities to exclude di(2-ethylhexyl) phthalate, a phthalate and plasticizer with endocrine-disrupting properties that can leach out of products and enter the environment, where it can be absorbed through inhalation, ingestion or skin contact.

CooperSurgical and Thermo Fisher Scientific report using reusable and recyclable alternatives to Styrofoam shipping boxes, including a recyclable paper cooler, which is described as a 100% paper-based container for shipping temperature-sensitive products, and Woolpack, which is a specialized sheep wool insulation, although this is currently only available in certain regions.

The Vitrolife Group reports that it aims to reduce emissions related to cold-chain transportation by informing customers about the transport's carbon dioxide emissions and encouraging them to buy larger quantities on fewer occasions. The company has also developed a calculation tool to ensure optimal filling of the cooling boxes. Non-cold-sensitive products such as instruments are transported by sea whenever possible. Vitrolife also reports working with professional freight forwarders that have efficient transport systems and those that optimize transport in terms of the packaging and transport route, to keep carbon dioxide emissions and costs down.

Many companies now recognize that 'circular economy' approaches are essential for sustainable operations; this means giving consumers incentives to use their products more efficiently and to 'return' waste, such as obsolete electronics, to the economy. When possible, some manufacturers recycle disposable products. For example, Cook has introduced a programme to recycle nitrile gloves. Thermo Fisher Scientific has utilized single-use plastic to produce shipping pallets, and Corning has recycled plastic for polypropylene pipette tip boxes. Vitrolife and Corning both report having improved opportunities for the recycling of packaging materials.

Each of the six companies declared its actions towards manufacturing efficiency, such as ISO 14001 or Leadership in Energy and Environmental Design (LEED) facilities certification, waste reduction and efficient water consumption. Two companies (Corning and Thermo Fisher Scientific) have aligned their GHG emissions reduction plans with the Paris Agreement and have reported on their progress. It is also encouraging to see that all companies examined here stated that their policy working with suppliers emphasized ethical and responsible practices, including taking actions to reduce the negative environmental impact of their operations through the supply chain.

Thus, overall, the industry supporting ART and IVF is aware of its critical role in environmental sustainability and some companies have undertaken efforts to reduce their negative impact. However, much more work remains to be done, and standards are yet to be established and followed. The information provided here is general – a first step in bringing awareness to the ART community. Close collaboration and communication with the manufacturers and suppliers serving IVF is still a necessity and will help to advance the goal of sustainability for both sides. Furthermore, a strategic alliance of large IVF clinics and networks to encourage manufacturers and vendors to implement sustainability strategies could be impactful

and play an important role in the industry's environmental performance overall.

Recommendations

- ART clinics and professional organizations should release periodic sustainability reports in a standardized and quantifiable manner, at either the national or international level, allowing for comparisons among clinics.
- To encourage reporting by supply and service companies, a standard questionnaire could be developed, which could be sent by clinics to the companies to obtain information related to their environmental impact and meaningful sustainability efforts. The information could then be considered by clinics when selecting suppliers.
- Environmental actions by supply and service companies should include improving product design, reducing hazardous chemicals, implementing environmentally friendly solutions for the packaging and shipping of products, water and energy conservation, transitioning to renewable energy sources and implementing effective waste management practices.

BENEFITS OF BUILDING GREEN

Charles Calcagni

Sustainability is impacting the building design and construction field. In Europe, sustainable practices are common, and in progressive cities in the USA, energy and sustainable practices are gaining traction as construction and energy costs soar. IVF laboratories, much like other areas of healthcare infrastructure, are expensive and energy intensive, requiring a substantial investment of materials and energy during their construction and operation. This section focuses on three basic concepts of sustainable construction: flexibility of design, materials selection and energy expenditure. With respect to location, considerations include easy access to public transport, availability of charging points and space for storage of bicycles.

Flexibility of design

Flexible laboratory design is crucial for futureproofing. With anticipated advancements in automation and workflows in the next decade, laboratories must accommodate changes without costly renovations or disruptions. This design approach requires collaboration between design professionals and building experts and stakeholders to align design decisions with laboratory processes. Creating open spaces with modular furniture allows for easy equipment and flow adjustments. Ultra-low outgassing steel and phenolic modular laboratory furniture enables quick changes while maintaining a clean laboratory environment. Accessible ceiling-mounted pipes and power lines facilitate convenient adjustments, while strategic gas supply points minimize costs and maximize flexibility. A minimalist design approach optimizes open space.

Materials selection

Materials selection in IVF laboratory design has evolved over the past three decades. Avoiding embryotoxic materials while opting for environmentally responsible alternatives is crucial. Locally available gypsum board, low volatile organic compound paints, silicone sealants and suitable glues contribute to sustainability and cost-effectiveness. With the building industry leading inflation worldwide and the shortages of material supplies having a profound impact on availability, it pays in every way to think sustainably and holistically, and plan for procuring locally when selecting materials.

Energy expenditure

In 1993 the US Green Building Council (USGBC) and later the American Institute of Architects created programmes to encourage industry-wide changes, monitoring energy efficiency and sustainability in construction. This is even more important today.

A sustainable approach to energy use can bring the largest savings in the construction and operation of laboratories. IVF laboratories require high levels of air filtration, which in turn require expensive air-handling systems with multiple filter banks *Mortimer et al., 2018*. Shying away from this significant expense, many laboratories use a less expensive heating, ventilation and air conditioning (HVAC) unit with an add-on filter bank in an attempt to save money. However, over time, this approach uses far more electricity and the savings at the outset will be easily eclipsed by the costs of operation and increasing energy costs. The introduction of an energy recovery ventilator and a dedicated outside air system as part of the HVAC design can achieve an energy saving of 15–30% compared with a typical constant-volume system with electric reheats. Maintenance is critical to the proper functioning of any mechanical system.

Existing laboratories with outdated mechanical systems present a challenge as it is often too costly (and unsustainable) to change these systems. Under those circumstances, buying green-sourced electricity from wind, solar and hydroelectric power suppliers is a short-term option.

There are many organizations that can help make the design and building of laboratories more efficient. The International Institute for Sustainable Labs (*I2SL, 2020*; *Environmental Protection Agency and US Department of Energy 2008*), Smart Labs Program, the USGBC LEED programme, and the Building Research Establishment in the UK's Building Research Establishment Environmental Assessment Method are several such organizations, with best-practice guides and certification programmes. Although not strictly for IVF laboratories, much of the information offered is helpful and translates well to the IVF environment.

Recommendations

- When designing a new laboratory, select design and engineering professionals with experience in sustainable laboratory design.
- When selecting a location, consider the proximity to public transport, charging points and bicycle storage areas.
- Use a minimalistic space design with flexibility to futureproof and avoid costly, energy-intensive construction when changes are needed.
- Use locally available building materials, considering both sustainability and non-toxicity.
- Aim for energy efficiency and the use of renewable energy.
- Buying green-sourced electricity from wind, solar and hydroelectric power suppliers is a short-term option for existing laboratories where retrofitting is too costly or not feasible.
- Consider widening operating ranges for temperature and humidity when possible.

ENVIRONMENTAL IMPACT THROUGH LIFE-CYCLE ANALYSIS

Cassandra L. Thiel

The healthcare sector must assess its resource use and minimize harmful

environmental emissions (*Sherman et al., 2021*; *Watts et al., 2021*). With financial and human resources stretched thin, however, decarbonization and pollution-reduction efforts should still achieve what they aim to do, and the only way to know if goals are being reached is to measure them. Quantifying environmental emissions from a product or process is possible through the use of tools such as carbon footprinting and life cycle assessment or analysis (LCA).

Carbon footprinting is often employed at the company or business level, with standards and guidelines set by ISO 14064, although carbon footprinting for products is also possible through ISO 14067. Emissions are often divided into 'scopes'. Scope 1 is anything directly emitted on site (e.g. waste incinerator or fossil fuel burning for energy production, and anaesthetic gases, which are potent GHG) (*McGain et al., 2021*). Scope 2 emissions are indirect GHG emissions associated with the generation of the purchased electricity, heating and cooling consumed by an entity. Scope 3 includes all activities related to the entity under analysis, including upstream transportation, waste generated, business travel, employee commuting, downstream transportation and distribution. At national and international levels, a majority of healthcare's emissions originate from Scope 3 activities — particularly single-use supply procurement and pharmaceuticals (*Eckelman et al., 2020*). Energy use (Scope 1 or 2 depending on the facility) is also high, with hospitals in the USA consuming more than almost any other commercial building type (*USEIA, 2016*).

LCA is a more comprehensive view of environmental emissions, including emissions to air, water and soil, and is guided by ISO 14040 and 14044. The emissions across a product or process life cycle are described by their impact; i.e. instead of simply listing emissions, LCA aggregates them into impact categories, such as GHG emissions or global warming potential, ozone depletion, particulate matter and the potential for eutrophication (a process that results from the accumulation of nutrients in bodies of water), also known as 'midpoint' indicators. LCA allows a further aggregation of emissions data into 'end-points' or damage categories such as disability-adjusted life years. LCA is more commonly used to assess products or smaller scale processes, since the data needs are intensive and LCAs can be labour intensive.

The use of LCA has been growing in the healthcare space. LCA has been used in many industries to identify 'hot spots' for pollution reduction efforts and to confirm sustainability claims about products and thus prevent 'greenwashing'. According to some reports (https://healthcarelca.com), as of April 2023 there were over 1400 healthcare-related products or processes studied via LCA in more than 80 countries, with the majority published since 2020. LCA is an important tool to guide decision making and decarbonization efforts and will be important to consider in pathways to Green IVF®.

There are existing LCA studies that may assist in assessing the impact of IVF treatments, although no IVF-specific LCA is available. Existing studies include the LCA of gowns, gloves, masks and processes such as surface decontamination, waste management, reusable device reprocessing and laboratory testing (*Thiel et al., 2015*; https://healthcarelca.com).

The first step of a life-cycle analysis is to set the goal and scope of the study, firmly identifying which components of the procedure (inputs) are or are not included. For example, an LCA of a hysterectomy procedure may include disposable supplies, reusable instruments, drugs and energy use, but might exclude the manufacturing of the capital equipment (*Thiel et al., 2015*). Data must be collected on all the inputs, including the types of material used, the weights of the materials and the amount of energy used. These can be collected from financial records, product specification information (from manufacturers) or through direct measurement (e.g. waste audits). Specialized software is typically required to map these inputs to emissions inventories (life-cycle inventories) and translate them into impact (life-cycle impact assessment). LCA should also include some assessment of variability or uncertainty, for example sensitivity analyses or Monte Carlo assessments, a computational technique that uses random sampling to obtain numerical results for complex problems or simulations.

The results of an LCA or a carbon footprint can identify 'hot spots' in a system — areas responsible for a larger percentage of GHG emissions. These hot spots represent opportunities for improvement; for example, a certain machine might be drawing more power than expected and might need to be replaced with a more energy-efficient one, or electricity sourcing could perhaps be improved to a less GHG-intensive supply. Understanding and tracking where emissions originate can help with policy making in an institution (e.g. creating a 'sustainable' or environmentally preferred procurement policy that prioritizes low-GHG supplies), purchasing decisions (e.g. data that support product selection) and advocacy (e.g. partnering with regulators, accreditors and manufacturers to create more sustainable products and systems). Advocacy and policy making are especially important when tackling Scope 3 emissions.

Although LCA typically focuses on environmental issues, sustainability must also address equity and social issues. Unfortunately, studies are lacking in the healthcare space, but it is known that equity is an important issue, not simply in relation to who receives care and how much they pay, but also in the labour practices along the healthcare supply chain. Studies have found child labour and forced labour among other issues affecting workers in the manufacturing of medical supplies (*Abbott and Bhutta, 2020*).

Recommendations

- Identify those IVF products or procedures where LCA or carbon footprinting data would be most useful, bearing the following in mind:
  - The most commonly used procedures or devices may present greater opportunity for impact, given their frequency of use.
  - LCA is best applied to comparative settings (such as multiple procedures/products with clinical equipoise).
- Identify settings where practice variability is occurring:
  - Different settings (health systems, countries, world regions) may conduct the same procedure differently. These variations can yield insights into performance improvements.
- Identify key value chain stakeholders, such as prominent manufacturers, who might partner in decarbonization efforts:
  - Scope 3 emissions are typically the largest for healthcare providers and institutions; thus, partnerships with manufacturers and suppliers are required to reduce these emissions.
  - LCA may be encouraged among product manufacturers who will be better able to provide the necessary

data and should be using them to inform product research and development decisions.
  - Other options include environmental product declarations, which are life-cycle-based standards for a specific product category set by industry.
- Identify educational opportunities:
  - IVF providers and other stakeholders, including patients, should be trained and educated on sustainability and the effect of climate change on reproductive health.

MANAGING WASTE IN THE IVF LABORATORY

Mina Alikani and Roisin O'Raghallaigh

Clinical and research laboratories are major producers of waste (*Lopez et al., 2017*). Proper management of this waste is paramount to sustainability and reducing the environmental impact of laboratories. The old paradigm of reduce, reuse and recycle is no longer sufficient. Instead, waste management strategies have shifted towards the avoidance or prevention of waste in the first place, for example through a careful assessment of procurement habits and needs, with recycling as the next option.

Recycling options are not always easily deciphered. As far as the authors are aware, there are currently no regulations in the EU, the UK or the USA to label products with information on recycling or other waste management options. Many companies do label products with recycling symbols (https://www.recyclenow.com/how-to-recycle/recycling-symbols), WRAP, n.d. but this varies from company to company and country to country. If labelling were to be improved, it could positively influence consumer behaviour and improve sustainability with appropriate waste disposal (https://www.medicalplasticsnews.com/medical-plastics-industry-insights/medical-plastics-sustainability-insights/how-labelling-can-play-a-role-in-reducing-waste-in-the-medic).

In the UK, a government programme called 'extended producer responsibility' for packaging is being implemented over the next few years (*Department for Environment, Food & Rural Affairs and Environment Agency, 2023*). Under these new rules, all UK organizations that import or supply packaging are required to collect and report data on their packaging. Recyclability labels will also be mandatory, either 'recycle' or 'do not recycle'.

The EU Directive 94/62/EC on packaging and packaging waste also aims for an extended producer responsibility scheme to be introduced by 2024, where the producer is financially responsible for the collection and most environmentally suitable disposal or reuse of the packaging. The EU has set out to achieve a number of goals, including, by 31 December 2025, the compulsory recycling of at least 65% by weight of all packaging waste, 50% of aluminium, 70% of glass and 75% of paper and cardboard. Products manufactured outside the EU and being sold within the EU must also meet these requirements so the rules can be expected to have a far-reaching impact.

IVF laboratory waste can be placed in three broad categories: general waste (including consumables and packaging waste), biological waste (including biohazardous material) and equipment waste (including computers and other non-functional or outdated equipment). Most prominently, consumables include plastics and disposable gloves (nitrile, latex or vinyl) and packaging waste includes Styrofoam or expanded polystyrene (EPS), gel and ice packs, plastic film, corrugate and paperboard. Biological waste includes all human bodily fluids (e.g. follicular fluid, blood and semen) and 'sharps'. This waste must be treated before disposal due to its potentially infectious nature.

So, what happens to all the waste created in our laboratories? A recent World Bank report (*Kaza et al., 2018*) estimates that about 37% of waste is disposed in landfills and another 33% in open dumps (70% in total); only 19% undergoes so-called materials recovery through recycling and composting, and 11% is incinerated (**FIGURE 2**). These figures may not be the same for waste generated by laboratories. But the World Health Organization (*WHO, 2018*) reports that, 'of the total amount of waste generated by health-care activities, about 85% is general, non-hazardous waste', which is defined as 'waste that does not pose any particular biological, chemical, radioactive or physical hazard' (*WHO, 2018*). This means that a proper segregation of laboratory waste can reduce the volume of waste that must either be incinerated or treated chemically to render it non-hazardous. According to a report by Thermo Fisher Scientific, a simple action such as replacing deskside waste bins with centralized sorting stations can not only reduce the volume of waste, but also lead to a significant decrease in the time spent by cleaners removing the waste (*Thermo Fisher Scientific, 2020*).

In the best scenarios, waste is collected, dried and burned as fuel to heat water, which produces steam that powers generators to produce electricity. However, there are concerns regarding emissions of GHG, pollutants such as dioxins, and toxic ash, which is released during this process, particularly with older incinerator technology (*Tait et al., 2020*). An alternative process is gasification – by heating waste with steam and oxygen to temperatures just below combustion, synthesis gases or 'syngases' (such as carbon monoxide, carbon dioxide and hydrogen) can be produced, which can then be used for fuel (https://www.biogreen-energy.com/syngas).

FIGURE 3 lists some commonly used disposable items in IVF laboratories and

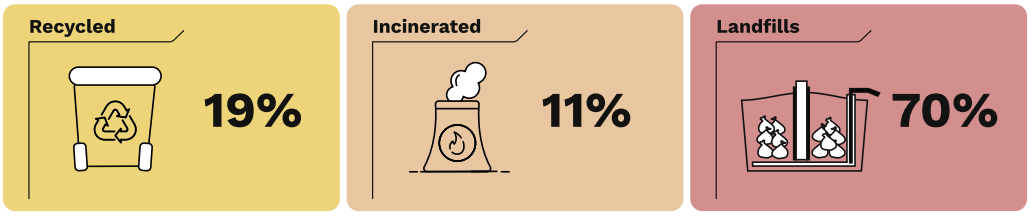

FIGURE 2 Management of global waste according to the World Bank (*Kaza et al., 2018*). A majority of the world's waste is disposed in open dumps and landfills or incinerated. A small percentage is recycled. The percentages for laboratory and healthcare waste are not available. Adapted from *Thermo Fisher Scientific 2020*.

potential ways in which the waste produced from these items can be avoided or diverted from incineration and landfills.

A few notes of caution are warranted. First, nearly every material will biodegrade, given enough time. Declaring a product biodegradable without attaching a specific time required for biodegradation is essentially meaningless. Second, the resources listed in FIGURE 3 are not exhaustive and may be unique to specific geographical regions, there are many other companies that may offer recycling and other responsible waste management services, and searching for local alternatives is prudent. Third, there is considerable controversy regarding the transparency and validity of claims made by recycling companies regarding recycling and waste-to-energy conversion (*Kaufman, 2022*). Investigating before selecting any company for such services is highly recommended.

Recommendations

- Focus waste management on preventing waste, reducing use of plastics and other single-use items to the extent that is possible and safe, and reusing what can be reused.
- Explore recycling and take-back options.
- Segregate hazardous and non-hazardous waste properly to avoid unnecessary incineration activity; seek guidance from local or institutional waste management services.

GREENING OF THE CRYO-CHAIN

Timothy Sharp, Mina Alikani and Giles Palmer

IVF laboratories across the globe are facing multiple challenges in the cryostorage of human gametes, embryos and reproductive tissues. These challenges stem from ever-increasing inventories of

Waste Item	Waste Management Approach	Alternative Options and Example Resources
Disposable caps	PREVENT	Fabric caps
Disposable shoe covers	PREVENT	Dedicated lab shoes
Plastic laundry collection bags	PREVENT	Fabric laundry bins
Disposable garments	PREVENT	Fabric garments
Disposable gloves Disposable garments Disposable safety glasses	REDUCE; RECYCLE	RightCycle TerraCycle Triumvirate: Red2Green
Pipette tips	REDUCE; RECYCLE (specialty)	TerraCycle
Pipette tip racks Microtool packaging	REDUCE; RECYCLE (specialty)	Vendor take-back programs TerraCycle GreenLabs Recycling
Serological pipettes	REDUCE; RECYCLE (specialty)	TerraCycle
Media bottles	RECYCLE (specialty; triple rinse)	TerraCycle
Cold gel packs	REUSE SEGREGATE	Vendor take-back programs Discard cellulose gel in trash, clean plastic film and recycle
Styrofoam (EPS) boxes	PREVENT; REDUCE; RECYCLE (specialty)	VeriCool Packaging Woolpack
Packaging material (bubble wrap, air pillows, plastic film)	REUSE; RECYCLE (specialty)	TerraCycle BagandFilmRecycling.org Gumtree
E-waste	RECYCLE (specialty)	Staples Call2Recycle

FIGURE 3 Commonly used disposable items in IVF laboratories and potential ways in which the waste produced from these items can be diverted from incineration and landfills. EPS, expanded polystyrene.

cryopreserved material stored at cryogenic temperatures (around −196°C) for longer and longer periods (*Abreau et al., 2021*) and an infrastructure that for the most part was not designed to handle such large volumes (*Alikani and Parmegiani, 2018*). The most common cryostorage formats are small dewars (30–73 litre capacity), the basic design of which dates to James Dewar in the late 19th century, and larger stainless-steel tanks (160–1000 litre capacity) for 'bulk' storage (*Pomeroy et al., 2019*). Small dewars are filled with LN2 and maintained manually, while the larger tanks are usually equipped with automatic filling systems and can function with either LN2 or nitrogen in the vapour phase.

The carbon footprint of cryopreservation and cryostorage is attributable to the LN2 production process as well as its transportation to and utilization by the end-user. LN2 is produced through cryogenic distillation, which involves distilling, cooling and condensing nitrogen gas from the air. This process in principle requires compressors to compress the air, heat exchangers to cool the air, and distillation columns to separate the nitrogen from other components in the air mixture, all of which require energy expenditure. Utilization of LN2, on the other hand, generates significant waste primarily through burn-off during transfer to and from storage tanks and storage itself.

Small dewars in particular are subject to significant heat transfer and nitrogen boil-off during daily activities of measuring LN2 levels and removing or depositing material. The frequent loss of LN2 necessitates frequent filling, LN2 supply deliveries and more logistics and supply chain costs, with a significant carbon footprint. LN2 supply tank deliveries are managed via large trucks because of the weight of the tanks, and the trucks use fossil fuels and combustion engines. Thus, any measures that can reduce LN2 use would lead to a reduction in the laboratory's carbon footprint.

Another potentially problematic aspect of cryostorage at IVF clinics is how LN2 is introduced into the storage containers. It is a common experience of users to hear hissing sounds when the LN2 tank valve is opened to dispense LN2. This is a sign that the process is resulting in excessive LN2 boil-off as the delivery hoses are cooled to allow liquid to flow. The alternative delivery system is an autofill system in which LN2 hoses or pipes directly feed dewars or large tanks, which reduce the amount of LN2 loss during filling events since the lines are continuously kept cold.

Tank dimensions also matter; for example, there is a significant difference in the boil-off rate of LN2 in a large-mouth tank compared with a small-mouth tank. When the lid of a tank is opened, it creates a vacuum that is filled by ambient air from the laboratory; i.e. heat is introduced into the tank. For the tank to eliminate that heat, it must boil off LN2. Thus, when a large-mouth tank is accessed, more nitrogen will be boiled off compared with a small-mouth tank.

One other consideration is the materials with which the tanks are constructed. Dewars are typically made of aluminium while larger tanks are made of stainless steel. Stainless steel conducts far less heat than aluminium, so the vaporization rate of LN2 in a stainless-steel tank is less than that in an aluminium dewar. The material is also relevant to the lifespan of the tank and the need for replacement. Stainless steel outlasts aluminium. This is why manufacturers warranty the vacuum on aluminium dewars for only approximately 5 years, while stainless steel systems are warrantied for 10 years, although in practice the latter can last much longer. Overall, a stainless-steel system is preferred because of reduced nitrogen use and a reduced impact on vacuum integrity through routine operations.

Increasing inventories of cryopreserved reproductive cells and tissues and the proliferation of gamete banks and banking are associated with increasing demand for transport across cities, countries and even continents. The transport of these uniquely defined and valued cells requires strict maintenance of the cold chain, currently achieved through the utilization of cryogenic or 'dry' shippers. These are small dewars that are 'charged' or cooled with LN2 but, for safety reasons, contain only nitrogen vapour during transport. The full export/import process involves the shipping of a charged dry shipper by the receiving laboratory or a transport company to the laboratory of origin, recharging of the shipper upon receipt by the laboratory of origin to ensure its integrity, disposing of any LN2 remaining in the shipper, loading and securing of samples in the shipper, and shipping of the dry shipper with samples to the receiving laboratory. All transport is carried out using commercial delivery services that may or may not be specialized in the handling of gamete and embryo transport; all such services use trucks for the transport, and delivery to the final destination may or may not involve air transportation.

Although the environmental impact of these activities has not been empirically determined, some efforts to do so are underway. For example, one company has 'developed an operating system to collect data on a global scale for the purpose of quantifying [this] impact' (*Cryoport, 2021*). Notwithstanding the lack of data, it can be safely argued that the import and export of gametes and embryos is carbon intensive in addition to involving the risk to the viability of the material. One strategy commonly employed in clinical trial applications is batching, where material is accumulated so that the logistics become economical. This approach could save resources (including LN2) and reduce the carbon footprint as well as the costs. Batching of material for shipment may be considered by IVF clinics; however, the safety and maintenance of the chain of custody and sample identification must take priority in this case. For reasons of sustainability and safety, clinics and their patients should consider transport decisions carefully and minimize these activities.

The biorepository community is mainly focused on reducing energy consumption. Although a survey of biobanks in the UK suggests that financial sustainability rather than environmental sustainability may be the driver for this strategy, it is also suggested that 'promotion of financial sustainability often had a positive knock-on effect for environmental sustainability goals' (*Samuel et al., 2023*). This industry has managed to extend technology upgrade cycle lengths as well as produce greater efficiency in the utilization of resources and monitoring systems. Solar energy is being used to help operate some biobanks. With proper battery back-up and proper monitoring, solar energy use is a safe alternative to energy drawn directly from the grid and may provide an option for IVF clinics.

There are both on-site and off-site options for the storage of legacy and active inventories of human reproductive cells and tissues. Whether one is a greener

option than the other is a complex question and not easily determinable. The challenge with both on-site and off-site models is the logistics of gametes and embryos being transferred in and out. The main difference between the two models is the scale of the equipment and use of resources. For example, a standard 280 litre LN2 source tank used as reservoir to fill multiple dewars has an approximately 20% boil-off rate at each dispensing event. By contrast, in a specialized repository, a bulk system is used that will be connected to all the tanks, with significantly less boil-off since the entire infrastructure is vacuum jacketed, preventing product loss.

Additionally, biobanks and biorepositories have more resources compared with a clinic; they are therefore more efficient. For example, using a Styrofoam cooler to dispense LN2 and to perform vitrification or to move specimens to and from the storage dewars or tanks leads to a significant loss of LN2, whereas in a biobank the use of a 'cryocart' makes the process much more efficient. Unlike a Styrofoam container, the cryocart is an insulated cooler with vacuum-jacketed walls, and thus it maintains LN2 content about four times longer than a Styrofoam container. Over time, this translates into lower resource consumption.

Another alternative to the transport of LN2 is in-house LN2 generation. This option can lower energy consumption and eliminate the need for the transportation of cylinders and tanks, potentially reducing GHG emissions. In-house systems can also generate nitrogen at a pressure and flow rate required for each application, reducing product wastage while improving safety by removing the need for handling high-pressure cylinders. However, the installation and operation of such systems remain complex, and with increasing electrical energy costs this option may become less attractive to IVF clinics.

Recommendations

- The focus of cold chain sustainability in the context of IVF should be a reduction in energy consumption.
- A reduction in energy consumption can be achieved with the use of bulk tanks, autofill systems, local LN2 production, and prevention of LN2 loss during routine activities.
- Consider batching samples, when possible, to minimize the frequency of shipments, and limit this activity to when it is absolutely necessary.

'GREEN IVF®': A LABORATORY CASE STUDY

Carol Loscher

Therapie Fertility (Dublin, Ireland) set out to improve the sustainability of its operations by participating in a certification programme administered by My Green Lab (https://www.mygreenlab.org/green-lab-certification.html). In June 2022 Therapie became the first IVF laboratory to successfully complete the certification programme as a green-level certified laboratory.

The certification process began with the appointment of project leaders from the embryology team with strong support from the senior management team in the clinic, who approved the investment of time and funds into this project. The leaders were central in coordinating the project, researching and engaging the entire embryology team, and encouraging knowledge sharing among peers working in other laboratories.

The next step was a baseline assessment engaging all team members in the form of an online survey, to identify existing good practices as well as opportunities for improvement. While the laboratory had taken a number of steps toward sustainability, including a paper-free clinic, new energy-efficient equipment and LED lights, other areas were identified for improvement. Once this assessment was completed, an action plan was devised, which included plans for regular laboratory meetings to discuss progress and the education of all staff. FIGURE 4 summarizes the baseline assessment, plans for improvement and final outcome of change implementation.

Digitization of the clinic and laboratory was achieved using commercially available software, including an electronic medical record system with a patient portal for communication and consenting. Other systems that were incorporated included electronic witnessing, quality management-specific applications and continuous monitoring systems for equipment.

A further focus was placed on 5 of 12 (FIGURE 5) key areas that could deliver the highest environmental impact with the most immediate results: waste management and recycling, energy expenditure, water usage, resource management and education.

Waste management is a considerable challenge in IVF, as it is in other areas. By implementing the correct segregation of waste, the laboratory saw a 400% increase in recycling and >30% reduction in clinical waste (also called hazardous or medical waste). A key contributor to this success was an initial bin placement survey and engagement with waste management providers to better understand their processes and specific requirements for each waste stream. The survey clearly identified incorrect segregation of waste as an issue, compounded by a lack of information from suppliers about options other than disposal for the copious amounts of packaging used for delivery of supplies.

The removal of unnecessary clinical waste bins and the introduction of a small green recycling bin at each workstation was a cost-effective strategy and, through interaction with suppliers and waste management providers, clear segregation pathways were outlined for the laboratory team. The cost and energy required to dispose of clinical waste is considerable and through these changes significant reductions were attained. Alternative recycling schemes were also established in the clinic, for polystyrene (EPS), glass, printer toners, batteries and electrical items, as well as the shredding of paper containing confidential information. The aim was set at reducing clinical waste by 50% overall in the clinic. Following the implementation of all the recycling measures, a repeat waste audit was conducted. The practical implication of this change was a reduction in the frequency of waste collection, saving the clinic €968/month or €11,600 year.

While recycling is important, it should be used after options to prevent, reduce and reuse/repurpose have been explored or exhausted. Procedures were assessed to identify where a reduction in plastic use could be achieved. For example, a reduction in the number of syringes used per embryo transfer procedure was found to be feasible, as was minimizing dish wastage with more accurate daily needs estimates. In some cases, a change of suppliers and products was considered, opting for bulk packaging in

	Existing Good Practice	Changes Implemented	Future Goals
Infrastructure Energy & Plug Load	• Use of LED Lights and PIR sensors • Equipment turned off when not in use • All equipment < 2 yrs old (energy efficient) • Electricity source 100% renewable	• Turned off non-essential equipment outside operation hours • Set up PCs to auto-update and turn off at 5pm daily • Replace AHU/HVAC to 80/20 recirculation and 100% electric	• Energy audit to be performed for clinic by registered contractor • Create energy action plan for business • Consider ISO standards (i.e., ISO 50001 (Energy Management Systems) and ISO 14001 (Environmental Management System)) • Consider ISO 14644-16, Part 16, Code of practice for improving energy efficiency in clean rooms and clean air devices
Purchasing & Resource Management	• Robust stock control - First in First Out (FIFO) • Consolidated orders • All accompanying 'paperwork' received digitally (e.g., COA, product inserts)	• Supplier engagement to understand sustainability framework and supply chain locations • Increase use of reusable cold shipping containers and recyclable packaging • Incorporate sustainability into internal supplier audits and product selection	• Encourage suppliers to adopt sustainable practices in manufacturing and supply chain • ACT environmental impact labels for IVF suppliers • Consider supplier selection criteria
Community (Education)	• Culture of change and engagement in clinic • Strong quality management system (QMS) in place • Commitment to invest time, energy and financial resources to achieve goals	• Lab education with regular lab 'green meetings' • Green Team established in wider clinic (clinical and non-clinical staff) • Sustainability Officer appointed across parent company • Incorporation of sustainability into QMS	• Increase role of sustainability goals in quality management • Publicize sustainable travel options • Encourage use of reusable cups and composting in clinic • Promote in-house events to encourage staff participation and sustainable behaviour
Waste Reduction and Recycling	• Paper-light laboratory • Use of electronic apps and medical records (EMR), E-Consents, Reflections App (IVFqc), QMS software	• Baseline assessment of clinical waste over 1 month period • Contact with suppliers regarding recyclable packaging • Education on recycling • Bin placement survey completed alongside staff training • Introduction of new recycling streams • Reduction in plastic usage via modification of protocols • Reduced unused dish waste via accurate counts and time limit for use per dish type • Fabric scrub caps • Re-purpose ice packs • Re-usable visitor scrubs and shoes	• Repeat waste audit following implementation of all recycling measures • Aim to reduce clinical waste by 50% overall in clinic • Consider using re-usable sheets, patient gowns, recyclable gloves etc. • Consider turning off tube warmers overnight or on days when not in use
Water	• Minimal water usage in lab, single sink for hand washing only • Appox 2L sterile water used per week for humidified incubators	• Low Flow aerator fitted into sink to reduce water flow by 50%	• Water conservation education with focus on outside lab and home

FIGURE 4 Case study: baseline assessment before My Green Lab certification, changes implemented after assessment, and plans for future improvements in sustainability of the IVF laboratory at Therapie Fertility Clinic post certification. ACT® Label, Accountability, Consistency, and Transparency Label (My Green Lab initiative); AHU, air-handling unit; COA, Certificate of Analysis; EMR, electronic medical record; FIFO, first in, first out; HVAC, heating, ventilation, air conditioning; ISO, International Standards Organization; LED, light-emitting diode; PIR, passive infrared; QMS, quality management system.

lieu of individually wrapped items and refusing polystyrene packaging peanuts in favour of other more sustainable packaging items. In addition, single-use disposable items were eliminated where possible; for example, disposable paper hats were replaced with reusable fabric scrub hats, and disposable paper garments and shoe covers were replaced with cloth scrubs and laboratory-only shoes. A majority of these changes led to significant cost savings.

Managing energy expenditure is equally challenging in an IVF laboratory operating continuously. Nonetheless, practical steps can be taken to meet these challenges, including purchasing energy-efficient equipment. When purchasing new

FIGURE 5 Key areas of focus for improving sustainability in the IVF laboratory and clinic. Figure adapted from My Green Lab.

equipment, consideration should be given to the energy rating or efficiency level.

Identifying non-essential equipment that can be powered down where and when possible is important for energy savings. Laminar air flow cabinets, tube-warmers and warming trays, straw sealers, personal computers and lights can be powered down when not in use and when feasible, while incubators, autofill LN2 storage vessels, refrigerators, freezers, continuous monitoring systems and HVAC systems cannot be turned off. The installation of LED lighting and sensor-activated lighting in store rooms and auxiliary rooms is strongly recommended where possible. LED lighting is commonplace for new installations and is less energy intensive than traditional incandescent lighting systems (e.g. a 12-watt LED light is equivalent to a 100 W halogen light bulb, for the same light intensity). Similarly, newer equipment is generally more efficient than older items.

The HVAC system responsible for the air quality in the laboratory is an energy-intense system that should be carefully considered in relation to sustainability measures. While HVAC systems are indispensable for supplying clean filtered air, the units are very often overspecified, and can account for 50–70% of the building's electrical use.

Strategies such as reducing air exchanges during hours of operation or outside normal occupancy hours, and broadening humidity or temperature ranges, would have a significant impact on carbon dioxide emissions and also the operating costs of an IVF unit. The pharmaceutical clean room industry is a leading example of how this can be achieved and international guidelines should be considered (e.g., ISO 14644-16) (*International Standards Organization, 2019*): Part 16: Code of practice for improving energy efficiency in cleanrooms and clean air devices). Newer technologies that permit demand-based ventilation by active monitoring of occupancy or particle count may provide a good alternative. The selection of a renewable energy supplier is also important. Given the importance of maintaining excellent air quality in IVF laboratories, any changes to ventilation controls must be performed in conjunction with cleanroom specialists, and air quality validation should be performed and monitored.

Education is another key aspect of 'going green'. Team members must develop a good understanding of the issues surrounding sustainability and how to take action to reduce the environmental impact of their work. Indeed education and sharing of knowledge is also key for a buy-in from all team members.

Participating in a certification programme is an option that laboratories should consider as a way to establish baseline sustainability, determine areas of focus for improvement, explore and implement changes, and measure performance based on data (see FIGURE 4). To ensure durability, sustainability policies could be developed and incorporated into the laboratory's quality management system; it is up to individual laboratories to develop policies that are appropriate to their specific circumstances. Apart from the My Green Lab programme described in this case study, ISO 14001 and the Laboratory Efficiency Assessment Framework can provide tools and resources for sustainability in science and a route to certification, although the latter programme is currently available only to academic research laboratories.

Recommendations

- Laboratory certification programmes should be customized for IVF whenever possible, allowing for flexibility based on the unique requirements of IVF laboratories as well as local and national regulations. Ideally, the certification process should be multidimensional and cover aspects related to patients, clinics, laboratories and the larger organization.
- Laboratory staff should understand the laboratory's supply chain and waste streams and become stakeholders in the effort to become sustainable.
- Consider sustainability as an element of quality and incorporate its elements into the laboratory's quality management system.
- Leadership and quality management teams should focus on a plan to promote a continuous improvement of sustainability, and advocate to suppliers to improve the sustainability of their products and services.
- Individual reproductive specialists and clinics should encourage a broad implementation of sustainability actions across different laboratories within networks.
- The strategy for waste management should be to prevent, reduce, reuse (repurpose) and recycle.
- Reduction of the use of consumables (dishes, media, etc.) in laboratory protocols should be considered to reduce waste generation and save costs.
- Energy efficiency such as plug load and a re-evaluation of HVAC should be a priority for all IVF clinics given the high operating costs and the possible design

and operational impacts on sustainability.
- Consideration should be given to reducing the number of air changes per hour outside operational hours or times of low occupation. Widening the acceptable and operational temperature and humidity ranges is recommended when feasible.

LEGISLATION, GREEN LAWS AND ENFORCEMENT IN ART

James Lawford Davies

Healthcare is subject to extensive regulation around the world. Within healthcare, ART is commonly subject to additional tiers of regulation, guidance and oversight. Much of this regulation is targeted at ensuring the quality and safety of the products and services provided in ART clinics. Historically such regulation has been largely blind to the environmental impact of its practical consequences. More recently, however, there have been moves towards recognizing the importance of sustainability and environmental impact when developing policy and regulations. This section looks at how the regulatory landscape is evolving, the challenges still faced and potential actions and recommendations for the future.

The health sector has a large carbon footprint. A recent study published by the UK National Health Service (NHS) as part of its 'Greener NHS' programme identified that the NHS accounts for around 4% of GHG emissions in England — on a par with the airline industry. Within that, pharmaceuticals and medical devices contribute a large proportion of GHG emissions, with medicines accounting for 25% of carbon emissions within the NHS (*NHS, 2022*). Although there are no data quantifying the ART sector's contribution within that, it is a sector that relies heavily on both pharmaceuticals and medical devices.

Like ART, the pharmaceutical and medical device sectors are tightly regulated, and a range of different legislative frameworks govern different aspects of the design, manufacture, use and disposal of products. A dominant feature of regulation in this area is to ensure the quality of the product, its efficacy and the safety of the end-user. Such policy goals are not always compatible with sustainability. A simple illustration of this is the regulatory requirement to use blister packs in the UK: these are intended to reduce the risk of patients overdosing but generate high levels of waste. Similarly, regulatory obligations regarding the compulsory inclusion of patient information leaflets with medicines also add to emissions and packaging waste — albeit that they are intended to help ensure patient safety.

There is also a likelihood that the 'culture of compliance' in the tightly regulated ART sector may inadvertently limit engagement with alternative behaviours that may be more environmentally friendly. Clinics have to comply with myriad different regulations and guidance, and in some jurisdictions, they are subject to regular inspections by regulatory bodies. If approved, licensed or authorized to provide ART services, there may be an unwillingness on their part to embrace anything that might risk undermining such authorization. Progress therefore requires regulators to be adaptable and to take environmental concerns seriously — which in turn requires their underpinning regulations and legislation to facilitate or require this.

In these circumstances, and in light of the imperative to moderate or remove the adverse impact of unsustainable activities on the environment, there is a need to consider how regulation may be adapted, refocused and (where appropriate) reduced. There are two different but related issues at play here. The first is to review and revise existing regulation to make it more supportive of sustainability and, where possible, to remove regulatory requirements that may be damaging to the environment. The second is to use regulation as a tool to require and/or encourage sustainability.

There are three main approaches that show how regulations may have potential for meaningful change (although with varying levels of efficacy):

- Top-down regulation that requires compliance and imposes sanctions on companies and clinics that do not comply (a stick).
- Bottom-up regulation and policy that encourages compliance through incentives, rewards and recognition (a carrot).
- Horizontal initiatives (company to company, company to supplier, investor to company, etc.) that encourage or require compliance.

Top-down regulation

The traditional form of regulation is to impose a requirement that is backed up by sanctions for non-compliance. Examples relevant to environmental issues in the UK are the Producer Responsibility Obligations (Packaging Waste) Regulations and the Packaging (Essential Requirements) Regulations, which impose compliance obligations on packaging waste producers and set minimum criteria for packaging. The UK has also imposed a new tax on the production and use of plastic packaging with less than 30% recycled content.

Bottom-up regulation

The UK NHS is a notable example of how positive engagement with the health sector might encourage compliance. The 'Greener NHS' programme cited above commits to two targets:

- Reducing the NHS carbon footprint for emissions it controls directly to net zero by 2040, with an 80% reduction between 2028 and 2032.
- Reducing the NHS carbon footprint 'plus' (for emissions that it does not control directly but can influence) to net zero by 2045, with an 80% reduction between 2036 and 2039.

Since an estimated 60% of the NHS carbon footprint arises from its supply chain, the NHS is using public procurement rules to effect change. It has published a 'Net Zero Supplier Roadmap' which states that, by the end of the 2020s, the NHS will not purchase from suppliers who do not meet or exceed its carbon zero commitments. Public procurement notices in the UK have already started to include green requirements, such as requiring bidders to provide a carbon reduction plan, confirming their commitment to achieving net zero by 2050 (*UK Government policy note 021, 2021*).

A similar initiative has recently been introduced in the EU through the EU Corporate Sustainability Reporting Directive (CSRD), part of the European 'green deal' (*European Commission, 2023*). The CSRD came into force on 5 January 2023 and EU member states must implement the new Directive within 18

months, aimed at establishing a modern, resource-efficient and competitive economy with no net GHG emissions by 2050.

Horizontal initiatives

Although regulatory compliance is most commonly achieved through vertical implementation, horizontal initiatives are likely to be a powerful force for change. Although they are not legislative, accepted business and commercial standards can become so ingrained that they become a form of soft law. An example of this is the growing interest among investors in the green credentials of companies when considering investment decisions. The consultancy Bain surveyed investors in the USA and found that 93% would walk away from an investment opportunity if it posed an ESG concern, and 50% report better investment performance as a key reason to incorporate ESG. Other stakeholders, such as employees and consumers, also encourage companies to consider sustainability through their choice of employer and product.

Given the significant role of the private sector and external investors in the IVF sector, this is likely to become a standard feature of investors' screening processes for IVF clinics and companies.

Challenges

- ART clinics and their suppliers are often highly and tightly regulated and will be unable to breach regulations, notwithstanding that those regulations may require actions that are environmentally harmful and/or unsustainable.
- Pharmaceutical and medical device regulations are primarily concerned with the safety of the end-user, which may be contrary to sustainability.
- The often-complex nature of pharmaceutical products and the importance of end-users' safety may mean that manufacturers are limited in their ability to quickly change the processes they use in order to improve sustainability.
- Pharmaceuticals and medical devices are typically supplied through complex global supply chains involving a large number of stakeholders, meaning that — even if regulations permit changes in practice — effective changes will require a high degree of collaboration and coordination.
- There is a lack of leadership and regulatory alignment in areas relevant to emissions and sustainability.

GREEN CONFERENCES AND EVENTS

Giles Palmer and Jacques Cohen

Conferences, workshops and industry events can have a significant impact on the environment due to the amount of travel involved, energy usage and waste generated. However, there are many ways to make these events more environmentally friendly. First and foremost is to reduce the number of in-person conferences (*Nathans and Sterling, 2016*). When in-person conferences are necessary or preferred, the selection of the location and venue, accommodation, travel and the way in which organizers and exhibitors participate will impact the carbon footprint (*University of Birmingham*, www.birmingham.ac.uk/conferences-and-events).

One way to make conferences and workshops more environmentally conscious is by choosing a location that is easily accessible to attendees, reducing the need for air travel. Additionally, it is important to choose a location that is environmentally friendly, such as LEED-certified venues or a location that utilizes renewable energy sources. Selecting a venue with a green policy that uses natural light and has a good public transport system can help reduce carbon emissions. Moreover, choosing a location that is local to most attendees can reduce transportation costs and carbon footprints. When planning events, factors like natural climate conditions and season of the year can be considered, aiming to reduce the need for excessive heating or air conditioning.

Accommodation is another important consideration for environmentally aware conferences and workshops. Attendees should be encouraged to stay at eco-friendly hotels or resorts, which may be LEED certified or use renewable energy sources. Attendees can reduce their energy usage during their stay, such as turning off lights and air conditioning when they leave their room. They can also be encouraged to carpool or use public transportation when travelling to and from the conference venue.

Travel is a significant contributor to the environmental impact of conferences and workshops. One way to mitigate this impact is to encourage attendees to use low-emission transportation methods, such as electric vehicles or public transportation. Additionally, virtual conferences and workshops are becoming increasingly popular and offer a sustainable alternative to in-person events. Indeed, the expert meeting reported here sets an example of how consensus meetings can be held successfully on a virtual platform. An in-person meeting would have been a less environmentally friendly option, creating a large carbon footprint for each participant. Carbon dioxide emissions from transport for conference attendance forms a large percentage of a scientist's carbon footprint (*Spinellis et al., 2013*). A virtual meeting can be convened at a time most convenient for the majority of stakeholders and the proceedings can be easily recorded for accurate transcripts and further analysis.

Virtual conferences offer several benefits, including reduced carbon emissions, lack of travel costs and increased accessibility to attendees. This must be weighed against the need to attend conferences and workshops in person — the most effective and efficient use of time and resources should be considered not just on an individual basis, but also at the company level. Each department and each professional should be responsible for creating a timetable and agenda of education events. There should be an appraisal of educational events and policies on the basis of estimating each person's need for further education, clearly setting a maximum number of events (international and local) that are necessary and pertinent to professional development.

Conference organizers and exhibitors can play a significant role in making conferences and workshops more environmentally responsible. One way to reduce waste is by providing digital copies of conference materials, such as schedules and presentations, instead of paper copies. For their displays and marketing, exhibitors should be encouraged to use sustainable (e.g. recycled) materials and avoid materials that require hundreds of years to degrade once disposed of. Merchandise or 'swag' is a common feature of conferences and workshops, but it can also be a significant contributor to waste. Exhibitors can reduce waste by either providing eco-

FIGURE 6 Green IVF® Action Plan. The ways in which IVF laboratories can move toward sustainability. Green IVF® is a Registered Trademark owned by International IVF Initiative (I3). Alpha Scientists in Reproductive Medicine has permission to use the Green IVF® name in this collaborative paper. A/C, air conditioning; ACT®, Accountability, Consistency, and Transparency; EMR, electronic medical record.

friendly items, such as reusable water bottles, or, better yet, helping to change this culture and expectations for such easily and often discarded materials and provide 'digital swag', such as discount codes or access to proprietary educational and other content. Conference organizers can consider hosting surveys that focus on environmental awareness and sustainability, providing attendees with the tools and knowledge they need to reduce their own carbon footprint. ISO standard 20121 offers guidance and best practice to help manage events and control their social, economic and environmental impact.

To encourage delegates who prefer not to travel, a reward system could be designed acknowledging a delegate's awareness of environmental issues and a more interactive hybrid or online experience could be created. By making these small changes, educational events can have a lower environmental impact and support a more sustainable future.

SUMMARY

This paper is intended to increase ART practitioners' awareness of the importance of sustainability in IVF laboratory practice. To achieve sustainability, cooperation between all stakeholders (suppliers, clinics, societies and governing bodies) is needed. The recommendations of the panel as well as other actions each stakeholder can take to reduce the carbon footprint of their operations are summarized in FIGURE 6, which can be used as a quick reference as well as a checklist. Addressing the industry's environmental impact can be expected to help improve the efficacy of ART treatments, ameliorate adverse reproductive outcomes linked to the environment and uphold our collective commitment to 'first do no harm'.

SUPPLEMENTARY MATERIALS

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.rbmo.2023.103600.

DATA AVAILABILITY

No data was used for the research described in the article.

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