Approaches to Greening Radiology

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The health care sector is a resource-intensive industry, consuming significant amounts of water and energy, and producing a multitude of waste. Health care providers are increasingly implementing strategies to reduce energy use and waste. Little is currently known about existing sustainability strategies and how they may be supported by radiology practices. Here, we review concepts and ideas that minimize energy use and waste, and that can be supported or implemented by radiologists.

Key Words: Sustainability; Image Greenly; Waste; Reuse; Recycle.

BACKGROUND

Reduce. Reuse. Recycle. This popular slogan was coined in the 1970s as a call to action to save the environment. The 3R's of waste management simply indicate to cut back on the amount of trash that is generated (reduce), use things again rather than throwing them away (reuse), and make something new from something that was thrown away (recycle). Examples include using durable bags instead of plastic bags for shopping (reduce), donating worn clothing or furniture for others to use (reuse), and separately collecting paper and cardboard that can be made into new paper and carton products (recycle) (1). Recently, radiologists and healthcare organizations are exploring how these principles can be adopted to make imaging services more sustainable.

The U.S. Environmental Protection Agency (EPA) has passed numerous regulations targeting clean water, clean air, and toxic waste. Certain industries are required to report levels of toxins that are released and are being held accountable for cleaning up toxic waste sites (2). It has been argued that environmental regulations impose undue cost burden on businesses decreasing their competitiveness in the market. However, reduced illness and death, improved air and water quality, health benefits to workers, and innovation spurred by environmental regulations could result in economic benefits that can offset costs (2).

The health care sector is a resource-intensive industry, consuming significant amounts of water and energy, and producing a multitude of waste in various waste categories, including regulated medical waste. It was estimated that in 2007 total effects of U.S. healthcare system greenhouse gas (GHG) emissions constituted 8% of total U.S. GHG (3). The largest contributing factors to GHG emissions were hospital care, physician and clinical services, and prescription drugs (4). Emissions stem mostly from energy intensive functions in hospitals, such as heating, ventilation, air conditioning (HVAC), food services, laundry, computing, and running equipment (5,6). The Healthcare Environmental Resource Center (HERC) provides comprehensive resources addressing all varieties of hospital waste and any rules and regulations pertaining to them (7). In addition, HERC shares information on successful greening initiatives (7).

Here, we identify opportunities for decreasing resource consumption and optimizing waste management in radiology and propose actions that can be implemented at the system, radiology department, and the individual level.

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CURRENT APPROACH

Awareness of opportunities for greening radiology is rising (8). Four goals for greening radiology have been proposed: (1) decreasing energy and water usage, (2) using biodegradable materials, (3) decreasing waste, and (4) recycling and/or proper disposal of waste (8). A key initial strategy is raising awareness.

Decreasing Energy Use

Many systems within Radiology run continuously. Limiting the environmental impact of this energy usage not only requires initial investment by healthcare facilities, but also interfacing with multiple stakeholders or departments throughout the facility, such as engineering, information technology, environmental services, food services, purchasing, human resources and more.

Engineering

Over the course of a year, 4 MRI scanners and 3 CT scanners use enough electricity to power a town in Switzerland of 852 people (9). The engineering of sustainable medical imaging devices is driven in part by the need for solutions in developing countries (10), and nowadays there are professional degrees in Sustainable Engineering that reflect a paradigm shift for this profession from "control of nature to participation with nature" (11).

Radiologists can foster sustainable engineering by collaborating with vendors to create sustainability strategies: Arizona State University recently installed a 9.4 Tesla MRI scanner that is cryogen-free (12), thus eliminating the use of the cryogenic liquid helium as a non-renewable resource and requiring less hospital space. Interestingly, advanced imaging technologies may also consume more energy; i.e., a 3T MRI unit consumes more energy than a 1.5T unit, and a 256-slice CT unit consumes more than a 64-slice unit (9). This emphasizes the need for collaboration in developing technology that advances clinical care while reducing rather than increasing the environmental footprint.

Larger enterprise-wide Green Radiology initiatives may be possible via academic-industry partnerships, such as a current partnership at the University of California San Francisco (13). This partnership is monitoring imaging device energy consumption to produce eco-friendly imaging states and enable carbon-neutral imaging services. This partnership also explores applications for low-field strength (0.55T) MRI imaging, which offers advantages for access to care and the environment due to being nearly liquid helium free and easier siting in more rural locations.

Knowledge gathered from life cycle inventories for MRI imaging has raised the question of whether the American College of Radiology Appropriateness Criteria should include a sustainability rating to promote imaging procedures with a lower environmental footprint when multiple modalities might be equally appropriate (14).

Shutting Off Monitors

Reducing energy consumption by reading workstation monitors can have a major impact on the energy consumption footprint in radiology (15-20). Two to four reading workstations consume the same energy as an average family household in Switzerland annually (15). The reading station has traditionally been overlooked as a source of high energy usage but turning off the monitors when not in use can be very effective (15,21).

Eliminating the stand-by mode and having workstations shut down after 1 hour of inactivity resulted in a nearly 50% energy consumption reduction (16).In radiology, approximately 84,000 kilowatt-hours (kWh) per year in energy usage could be saved if all workstations were shut down after the normal workday (16). For reference, the average U.S. residential utility customer consumed 10,715 kWh in 2020 (22). Inactive stand-by mode for workstations also leads to excess heat production which may cause excess HVAC usage to maintain operating temperatures, further increasing energy use. Currently, information technology (IT) updates that are routinely pushed to workstations during stand-by times may necessitate leaving computers on throughout the day and night and would need to be addressed.

Lighting

Using highly efficient lighting, including lighting control systems and energy efficient bulbs, can create annual energy savings of 0.12 kWh/m2 in hospitals with a payback period of less than 2.2 years (23).

Many areas within a radiology department may be unused for portions of the day, such as exam rooms, office spaces, or meeting spaces. The most common lighting control methods include daylight sensor and motion sensor devices (24). Daylight sensors turn on lighting systems in response to the lack of natural light. Motion sensor technology turns on lights in response to occupant motion. Depending upon sensor location, passive occupancy (relative absence of motion) can result in the lights turning off inappropriately. Newer commercially available control methods combine each of these methods with ultrasonic technology which detects whether a person is still in the room. The use of lighting control devices could yield a 7% reduction in energy consumption (25).

Using energy efficient bulbs can also reduce the energy consumption for hospitals and radiology departments. Traditional incandescent bulbs remain widely used due to relative low cost, dimmability, and because they light up instantly. Fluorescent bulbs can generate the same illumination with a much longer lifespan of 7000-24,000 hours compared with 750-2400 hours for incandescent bulbs, all the while utilizing 25%-35% less energy than incandescent bulbs.

More recently, light emitting diode (LED) lights are becoming widely available and offer approximately 75% less energy compared with traditional incandescent bulbs. One of the perceived shortcomings of LED lighting is correlated color temperature (CCT) referring to the color of the source light when viewed directly. Various LED light colors (wavelengths of royal blue, green, amber, and red) can be combined to mimic the "warmer" light of traditional incandescent bulbs that is desired in clinical practice (26).

Climate Control

Heating, ventilation, and air conditioning (HVAC) uses technology to control air temperature and air purity within an enclosed space. Hospital HVAC systems generate the highest consumption of energy (65%) and $C0_2$ emissions (47%) (27,28).

Most diagnostic radiology equipment must be maintained at a consistent temperature controlled by HVAC, and the energy consumption of dedicated cooling systems comprise nearly 50% of the total energy needed; the largest share of energy consumption, approximately two-thirds, takes place during the nonproductive idle system state (9). In interventional radiology, as much as 57% of HVAC energy is used outside scheduled working hours when few procedures are performed and rooms are typically unoccupied (29). HVAC systems could be modified to operate between a wider range of temperatures outside scheduled working hours to save energy (29).

With regards to air quality, it is estimated that air conditioning growth alone will add approximately 132 to 167 GT of CO2 emissions through 2050, leading to 25%-50% of the remaining calculated carbon budget and exceeding the remaining budget projected through 2100, potentially derailing the Paris Agreement goal (30). Interventional radiology generated approximately 23,500 kg CO_2 during an audit of 98 procedures (mean 243 kg CO_2/procedure), which is equivalent to the carbon sequestered by 29 acres of U.S. forests in one year or CO_2 emissions from charging 3 million smartphones (29).

Modern HVAC systems control the indoor environment by detecting and responding to parameters such as air temperature, CO_2 concentration, humidity, and air flow rate and adjusting its function to an optimal value. Systems that only use one parameter consume excessive energy and do not achieve optimal air temperature or quality. Adaptive variable air control systems, with a feedback control system to adjust to a changing environment, consume less energy. With COVID-19, it has become important not to recirculate air or to maximize the outdoor-air level (31).

"Integrative design" is a holistic approach to building energy-using systems that can allow substantial improvements in efficiency by shrinking or optimizing HVAC equipment. There is evidence of the environmental and economic impact of replacing low-performing HVAC with new and high-performing HVAC. In addition, building design, including natural ventilation, efficient thermal insulation, and adequate sizing of space, are key (23). Benchmarking the energy efficiency of buildings is important for optimizing energy use and reducing the carbon footprint. In healthcare, difficulty of collecting energy data from many healthcare facilities has made it challenging to develop an appropriate benchmarking system (32).

Decreasing Waste

Going Paperless

While the cost of purchasing paper is low, the cost of managing paper (storing, copying, printing, disposing, etc.) can be up to 31 times higher (33). Replacement of paper medical records with electronic health records (EHR) in the U.S has yielded a financial 5-year net benefit of $86,000 per primary care provider, with the majority of the savings related to lower drug expenses, decreased billing errors, better capture of practice charges, and improved use of radiology studies (34). It is conceivable that part of such savings comes from reduced cost related to paper record management, although there are no studies that have specifically evaluated this aspect.

Despite the widespread implementation of EHR systems, many medical centers continue to have difficulty with moving completely away from using paper. Many reasons for continued paper use exist, such as long-term familiarity with paper or simply valuing the palpable presence of paper "to have the information on paper where I can hold onto it" (35). Persistent paper use is very prevalent in medical billing, even though 86% of healthcare consumers pay recurring bills online (36).

Many physicians, including radiologists, may need to take notes during the workday. Interestingly, paper notebooks outperform digital tablets in most environmental impact categories. Tablets produced more health-related impacts and ecotoxicity while the notebook produced more land-related impacts and ozone depletion (37). The key ecotoxicity factor lies with the number of pages of paper used, so using small sticky notes or re-using special notepads with erasable pens could be impactful. Digital note taking apps that run on a workstation desktop would both avoid paper use and obviate the need to purchase separate digital note taking devices. Additional opportunities for saving paper in radiology include purchasing digital textbooks or used books and reading scientific journals online.

Food

The environmental impact from food services is related to production/procurement, distribution, preparation, consumption, or waste management/disposal (38). The environmental impact that has been most widely explored is food waste (38). Among the strategies to reduce food waste in healthcare is the Room Service model. Unlike the traditional model that offers patients little to no choice with regards to the type of food they want to eat and when they want to eat it, the room service model allows patients to order meals a la carte anytime between 06:30 and 19:00 by calling a central call center (39). This system reduces the number of food items remaining on a plate after a meal from 30% to 17%, reduces food costs by 28% per annum, while increasing patient satisfaction (39). A similar concept could be applied to cafeteria food, where customers choose their own amount to eat and pay accordingly. Encouraging staff to use washable and reusable personal cutleries and plates can also be helpful (8).

Purchasing

An organizations' purchasing decisions can have considerable adverse social and environmental impacts. Green Purchasing or Environmentally Preferable Purchasing (EPP) are terms used for purchasing products with reduced impact on human health and the environment when compared to other products of the same functionality. Incorporating EPP as a purchasing strategy involves raw materials acquisition, production, fabrication, manufacturing, packaging, distribution, reuse, operation, maintenance, and disposal of the product. It also includes using recyclable products, recycled materials, reusable products, and products that conserve energy or natural resources. Evaluation of these factors is simple when an environmental product declaration (EPD) is available, which transparently communicates the environmental impact of a product over its lifetime, akin to nutrition labels on food (40).The National Association of State Procurement Officials (NASPO) has released a comprehensive green purchasing guideline, which could be considered and incorporated into policies and decision making at health care institutions (41).Key purchasing strategies include sourcing materials locally to decrease transportation, buying supplies from energy efficient companies, reuse, and consider integrating biodegradable materials when possible.

Reusing

All industries, including healthcare, will need to transition from a linear to a circular economy to meet climate goals. In a linear economy the smallest stopcock and the largest imaging equipment all are designed to be single use, to be disposed of at the end of their life cycle. The life cycle inventory is a tool for quantifying the environmental impact from equipment. For example, a life cycle inventory for an MRI scanner would include raw materials required to build the MRI scanner, resources consumed to install and use the device, disposing of materials at the end of life, and carbon emissions linked to transportation (42).

In a circular economy medical equipment would need to be designed and manufactured as modular, upgradeable and recyclable. Studies comparing single-use versus reusable equipment reveal that single-use disposable products typically result in several-fold higher petrochemical use and global GHG emissions (43–45).

It appears to make sense that donating unused radiology equipment to recipients who could not otherwise afford such equipment would meet the sustainability criteria of "reusing." However, such donations could quickly turn into waste if disadvantages outweigh cost savings for recipients (46). For example, equipment donations are not cost effective if the recipient may be unable to absorb the technology (skilled operators, ancillary equipment, maintenance capability) or the equipment may become obsolete within 2 years (unavailable maintenance part or maintenance services) (46,47)] The World Health Organization (WHO) issued guidelines for donating equipment to developing countries that seek to improve donation utilization by recipients (47). Summarized, WHO promotes four principles for medical equipment donations: (1) Donations should have maximal recipient benefit, (2) donations should be given with due respect for the wishes and authority of the recipient and conform to local government policies, (3) donations should have no quality double standard, and (4) donors and recipients should engage in effective communication throughout the donation process (47). However, an analysis of medicine and medical device donations has shown that most donations did not comply with the WHO guidelines and none of the donation reports provided enough information to completely assess the donation compliance with the guidelines (48). Developing equipment with the specific conditions of a low-resource environment in mind, such as equipment with lower power requirements or adoption of cloud PACS, may be more sustainable than equipment donations (49).

Reusable surgical gowns are FDA-approved for seventy-five reuse cycles and may be an option in some radiology areas. Single-use gowns can generate up to sevenfold more solid waste and double the amount of global GHG emissions compared with reusable gowns (50). Reusable medical gowns that can be industrially laundered outperform disposable gowns in terms of protection, durability and sustainability and thus could be considered for use throughout radiology departments (51). In another example, the University of Vermont recycles all blue plastic surgical drapes, transfers them to the University's processing site where they are made into plastic pellets which are molded into plastic products such as bed pans (52). There may be opportunities for refilling materials, such as hand sanitizer. Large Radiology departments and Healthcare Systems that are committed to sustainability can leverage their purchasing power to transform the healthcare economy from a single use linear one to a multi-use circular economy.

Event Hosting

Medical events should have a smaller carbon footprint (53). The largest radiology conference hosted by the Radiology Society of North American (RSNA) generates 43,557 US tons of travel-related CO2-equivalent emissions (54). For reference, this equals the average annual carbon footprint of 1308 US households [Feng 2021]. Holding events virtually could have a significant environmental impact (53). At a much smaller scale, this may also be true for local meetings that may require local travel, such as clinical and trainee conferences, departmental/practice meetings, retreats, etc. (53). Additionally, a checklist for hosting eco-friendly meetings also suggests raising awareness for sustainable and carbon-neutral events among attendees, reduce meat and dairy products to reduce carbon emissions, and use smaller plates to minimize food waste, avoid disposable materials and ask attendees to bring their own cups, plates, and cutlery, and provide waste sorting bins (53). Radiology residency and fellowship interview travel results in airplane and car emissions, potentially significantly reduced with virtual interviews (and with significant cost savings for all involved) (29,54). A comparison of in-person versus virtual interviews for fellows identified shortfalls of the virtual format with regards to conveying the program's culture and more subjective aspects of the program (55). Evaluating the effectiveness of virtual meetings and interviews could inform future mixed approaches or refinements to the virtual process.

Attendees of the Radiology Society of North American (RSNA) annual meeting just over 40% of the attendees' CO2-equivalent emissions totaled 39,506,038 kg with a calculated CO2 offset cost of $474,072 USD (56). More than 90% of the S&P 500 companies publish sustainability reports, perhaps we can do the same in healthcare and/or radiology (57).

Teleradiology

Fueled by the COVID-19 pandemic experience, there is increasing demand for teleradiology and hybrid practice positions, which have the potential to decrease pollution and energy use related to transportation.

Packaging

Disposable surgical waste contributes significantly to the GHG generation from an IR department. The GHG generation from disposable medical supplies can be reduced by redesigning packaging, sorting disposable waste, and optimizing supply sourcing (29,58-61). In fact, a study determined that waste from packaging that is non-essential to the function of a medical device constitutes around 55% of the total weight of medical supplies waste, and approximately 76% of this waste is potentially recyclable, but only a small portion of it is, in fact, recycled (59). Radiologists can advocate for redesigning packaging to reduce the number of packaging layers. In addition, paper instructions can be replaced by digital versions (60−62).

Anesthesia Gas

Gas anesthetics are a big contributor to GHG generation in most surgical; however, this is less true for IR as the majority of IR procedures are performed under moderate sedation (29,63). Nonetheless, when general anesthesia is utilized low-impact gasses and the use of low fresh gas flow technique during the maintenance phase of the anesthesia can be advocated for (64).

Biodegradable Items

Examples of replacing single-use items with biodegradable products include drinking cups made of cornstarch (8).

Recycling and/or Proper Disposal of Waste

Waste Segregation

During a radiology interventional procedure, waste is commonly disposed of as either solid waste or regulated medical waste. Regulated medical waste requires additional energy intensive treatment prior to final disposal (65). Proper segregation strategies can therefore improve the GHG footprint both by increasing the percentage of packaging which is recycled and by reducing the volumes of regulated medical waste (66). Prime targets for optimizing the segregation of waste are when the technologist sets up the room before the procedure starts, during the procedure, and after the procedure (67). Before the interventional procedure, none of the waste generated is regulated medical waste and should be sorted into recyclable and solid waste. This pre-procedural waste can be disposed of in a separate solid medical waste container which can be lined by a clean bag and labeled for easy distinction. During the interventional procedure, with appropriate training and team education, waste segregation can be done as the procedure goes on by keeping solid waste disposal and regulated medical waste containers that are easily identified and appropriately labeled. Similarly, after the procedure, unsoiled and unused items can be identified to again allow for separation into regulated medical waste, solid waste, and recyclables. Similarly, waste can be segregated in other radiology areas (Fig 1).

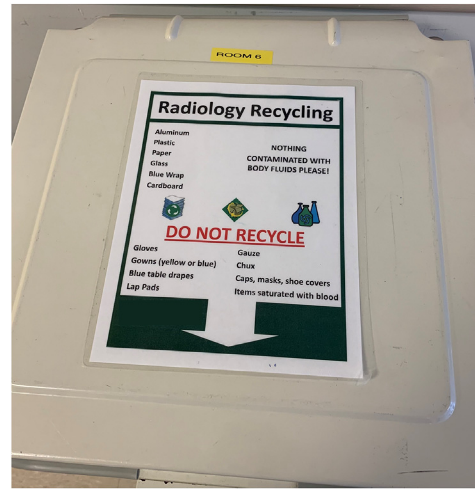

Figure 1. Sorting Waste for Recycling. Trash can in the radiology reading room encouraging separation of waste with clear instructions on what and what not to recycle. (Color version of figure is available online.)

Waste Transportation

Medical supplies are often transported as individually boxed items across international borders and state lines to different hospitals, which significantly contribute to the overall GHG production (29)]. An effort should be made to use supplies that are produced locally or in nearby regions so that multiple products can be transported in a single package to reduce the environmental effect of transportation (68). Just-In-Time (JIT) purchasing has been shown to reduce waste (69).

Raising Awareness

Increasing awareness of the effects of climate change can cause feelings of hopelessness and cynicism among staff. This represents an opportunity to motivate individuals and work systems to take meaningful actions.

As a first step, it is important to help staff understand how climate change will and does adversely affect individual and population health through degradation of the social determinants of health, such as clean air, safe water, safe and adequate food and housing. According to the WHO, the direct costs to health is estimated to be between USD 2-4 billion/year by 2030, with 250, 000 anticipated additional deaths per year, from malnutrition, malaria, diarrhea and heat stress (70).

To raise awareness, impactful campaigns may be initiated by national radiology organizations, similar to the "Image Wisely" (71) or "Image Gently" (72) campaigns, where radiologists can pledge to their commitment to "Image Greenly" (Fig 2) and access educational resources. Perhaps a goal of carbon neutrality may be aided by organizations like the American College of Radiology having a "green" accreditation. Additionally, Hospital and Radiology department campaigns could include a focused journal club, inviting speakers, and task forces to identify and realize greening opportunities. Individual staff members may share information on public transportation options or ride shares, encouraging green behaviors such as re-using cups.

Effective engagement of all members of the radiology practice is of utmost importance to greening radiology. A strategy to foster positive individual and organizational behavior includes focusing and investing in employee well-being (72). In the concept of Healthy and Resilient Organizations (HERO), healthy practices in an organization are associated with higher teamwork engagement and higher levels of trust (73). Three easy steps to follow are: (1) encouraging people to break the old habits, (2) developing new habits (incentives help), and (3) repeated response processes naturally become a new attitude (74).

Inspired by the sustainability slogan, "Small actions can make a big difference," individuals can make simple contributions in day-to-day life toward a greener world (75). After all, it is eventually up to the individual user to remember to power-down any computer or workstations that are not being used and to switch off lights in rooms that are unoccupied, such as staff offices, meeting spaces, bathrooms, utility rooms, breakrooms, etc.

Figure 2. Image Greenly Logo. The AUR-RRA Greening Radiology Task Force vetted the idea of a "Image Greenly" campaign, to add to existing "Image Wisely" and "Image Gently" campaigns. The artwork was created by Emory Healthcare Marketing. (Color version of figure is available online.)

CONCLUSION

Radiologists and healthcare organizations have many opportunities to make smaller and larger contributions towards a greener environment. The most impactful actions that can be taken fall under the auspice of operational leadership within radiology practices. Leadership and advocacy from radiologists are most important to raise awareness of greening opportunities in radiology and to implement and report on successful greening radiology initiatives.

AUTHOR CONTRIBUTIONS

	Conception and design, or acquisition of data, or analysis and interpretation of data	Drafting the article or revising it critically for important intellectual content	final approval of the version to be published	Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved
Sumner	X	X	X	X
Ikuta	X	X	X	X
Garg	X	X	X	X
Martin	X	X	X	X
Mansoori	X	X	X	X
Chalian	X	X	X	X
Englander	X	X	X	X
Chertoff		X	X	X
Woolen		X	X	X
Caplind	X	X	X	X
Sneider	X			
Desouches	X	X	X	X
Chan		X	X	X
Kadom	X	X	X	X

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