BOSTON MEDICAL CENTER

Addressing Waste-Related Emissions in Healthcare

Waste audits at Boston Medical Center reveal opportunities to reduce greenhouse gas emissions and generate cost savings

The project described in this report was executed in collaboration with

Three key factors drove emissions:

1 Disposal processes

2 Waste volume

3 Packaging materials

Executive Summary

Boston Medical Center (BMC) and Takeda have completed the first year of a groundbreaking three-year collaboration to identify and address greenhouse gas (GHG) emissions hotspots across the healthcare value chain. In-depth waste audits in BMC's pharmacies and infusion center revealed significant, readily attainable opportunities for emissions reduction. Three key factors drove emissions: waste disposal method, waste volume, and packaging material type. Emissions vary by disposal method, with regulated medical waste (RMW) among the most emissions-intensive because it is sterilized before disposal. Although RMW represents only 4% of BMC's waste by weight, it accounts for 25% of waste spending and 30% of waste-related emissions. We found that 75% of audited RMW could have been recycled or disposed of as regular trash, a lower-emissions option. Improved sorting therefore represents a near-term, high-impact intervention to cut emissions and generate cost savings. Pathways to reduce waste volume include more efficient medication handling—particularly for liquid drugs—and transitioning to reusable items such as ice packs. Switching to lower-emissions material types can be achieved through increasing use of reusable, biobased/biodegradable materials, or readily recyclable packaging and supplies. An example is a recyclable, paper-based prescription bottle, which recently became available on the market. Over the next two years, BMC and Takeda will leverage the audit findings to develop, pilot, and begin to scale solutions. Ultimately, we will partner with peer health systems and other stakeholders to scale interventions for maximum impact and value creation.

Regulated Medical Waste (RMW) represents:

4%
of BMC's waste by weight

25%
of waste spending

30%
of waste-related emissions

TOP 5
types of waste in RMW, by weight:

1. IV Bag / Tubing
2. Glass Vial
3. Syringe
4. White Plastic Pill Bottle
5. Plastic Cap

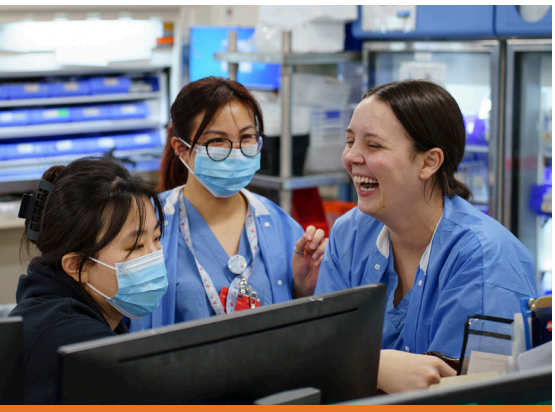
BMC and Takeda Embark on a "First-of-its-Kind" Collaboration

Takeda and Boston Medical Center (BMC), part of Boston Medical Center Health System, jointly recognize that climate change presents a profound threat to public health and the global healthcare sector. The wellbeing of patients is directly connected to the health of the planet. As a safety-net hospital, BMC serves many patients who have long faced disproportionate harm from pollution and climate change. BMC's sustainability commitments are therefore deeply aligned with its mission to improve the health of its patients and surrounding neighborhoods. Similarly, Takeda has a decades-long record of reducing the environmental impacts of its operations by integrating sustainability and environmental stewardship as a core component of its business strategy.

Both organizations have made ambitious public commitments to reduce greenhouse gas (GHG) emissions. Takeda has set a target of achieving net-zero emissions in its operations (scopes 1 and 2) by 2035 and across its entire value chain (scope 3) by 2040. BMC has committed to achieving net-zero emissions across its operations and supply chain by 2050. Because over 80 percent of BMC's carbon footprint comes from supply chain emissions, novel solutions to address these sources are central to its sustainabillity strategy.

Takeda and BMC recognize that achieving meaningful reductions in scope 3 emissions requires cross-sector collaboration. As a pharmaceutical supplier to BMC, Takeda impacts upstream emissions that fall within BMC's scope 3 footprint. As an end-user and dispenser of pharmaceutical products, BMC impacts Takeda's downstream scope 3 emissions through its waste handling procedures and the practices of its waste vendors.

A BMC-affiliated waste contractor assists with collecting sharps waste for the waste audit; a BMC infusion center nurse disposes of chemotherapy waste.



BY THE NUMBERS

80%

of BMC's carbon footprint comes from scope 3

BMC has committed to achieving net-zero supply chain emissions by

2050

Healthcare systems account for

8.5%

of U.S. GHG emissions

Despite growing momentum to decarbonize the healthcare supply chain, many hotspots remain in areas where low-carbon alternatives are not yet available or where existing solutions face barriers of scalability or feasibility. This collaboration was established to jointly identify, design, and implement solutions in these hard-to-abate areas.

Healthcare systems account for 8.5% of U.S. GHG emissions, with supply chain—including waste management—accounting for approximately 80% of that. Regulated medical waste (RMW), which is infectious or sharps waste, is a particularly hard-to-abate source of emissions. RMW is treated through energy-intensive processes such as incineration or autoclaving, resulting in disproportionately high emissions per pound compared with other waste streams. Single-use plastics in packaging and medical supplies present another major challenge. Plastics are widely used in healthcare due to their lightness, durability, design flexibility, and disposable nature, which reduces infection risk. However, plastics generate significant emissions across their lifecycle and are a major source of pollution. Emerging studies are finding microplastics, tiny particles of degraded plastic, in all parts of the human body with direct implications for human health.

This report marks the completion of the collaboration's first year, which focused on gathering baseline data to identify GHG emissions hotspots within BMC's pharmaceutical waste streams. The data presented here was gathered during waste audits conducted across three sites on BMC's campus. These results will guide the development of new models for reducing emissions associated with pharmaceutical waste, with with particular attention to regulated medical waste and drug product packaging.

BMC and Takeda now seek to disseminate these results—along with the key implications and opportunities they reveal—with peers across the healthcare sector. Because we found limited publicly available guidance on best practices for waste audits in a healthcare setting, we have also included a **Waste Audit Guide** to support other health systems and independent pharmacy teams in conducting their own audits.

Key Findings from Waste Audits

BMC's Environmental Health and Safety Team sort waste for the BMC audit.

Scope and Methodology

BMC conducted waste audits at three locations on its campus: the inpatient pharmacy, the largest outpatient pharmacy, and the infusion center, where intravenous medications are administered. These sites were selected because their pharmaceutical use and waste profiles significantly overlap with Takeda's supply chain.

BMC worked with Clinically Sustainable Consulting, a consulting firm specializing in medical waste analytics, to develop a Waste Audit Protocol. It details each step in the process: identifying key partners; building a database; collecting waste; sorting waste and collecting detailed data on each item; and analyzing the data to generate useful insights.

While originally tailored to BMC, the Waste Audit Protocol has been adapted into a **Waste Audit Guide** for general use to provide guidance to other health systems and pharmacies seeking to conduct their own waste audits.

To the best of our knowledge, no other U.S. health system has conducted a comprehensive waste audit of a pharmacy or infusion center, and we hope this toolkit will serve as a useful guide for future pharmacy waste audits.

Plastic medication containers identified during the BMC Outpatient Pharmacy audit. Packaging design and material selection influence end-of-life waste impacts.

Chris Goncalo, BMC's Director of Inpatient Pharmacy Operations, speaks with Anna Goldman (left), BMC's Medical Director of Sustainability, who led the audit, and Johanna Jobin (center), Takeda's Global Head of Environment and Sustainability.

In each of the three audits, all waste from every waste stream was collected over a predetermined time period. The waste was then sorted, photographed, and cataloged in a database. For each item, data collected included weight, material composition, packaging type (e.g., IV bag, syringe), brand or manufacturer (when available), and percentage used (e.g., the amount of remaining medication in the primary package). Greenhouse gas emissions were estimated using a material-level life cycle analysis (LCA) aligned with ISO 14040/14044 standards. Information on waste handling practices for each waste stream—including regulated medical waste—was gathered from respective waste vendors to accurately estimate emissions associated with the transportation and treatment of wastes leaving BMC audit locations (See Figure 1 on page 13). The resulting GHG data, reported in kilograms of carbon dioxide equivalents or kg CO_2e, were analyzed to estimate GHG emissions by individual waste item, packaging category, material type, site, and waste stream.

Key results overview

What drives waste-related greenhouse gas emissions?

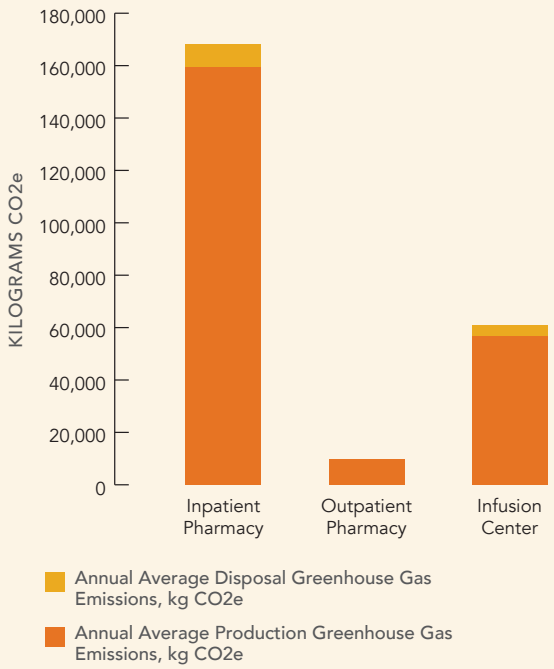
Analysis of the audit data revealed that three primary factors are responsible for BMC's waste-related emissions: disposal method, volume, and material type.

Certain disposal processes, such treatment of regulated medical waste and handling of waste that contains protected health information (PHI), create more emissions than other methods, such as recycling and municipal solid waste (regular trash). BMC's RMW emissions are 27 times higher than its municipal solid waste emissions, see figure 1. RMW leads to higher emissions because it is transferred first to a facility for sterilization, by steam autoclaving, microwave technology, or chemical sterilization, before finally being disposed of in landfills or waste-to-energy facilities. The extra transport step and the energy required to sterilize the material both contribute to excess emissions compared to municipal solid waste. PHI waste generates 12 times more emissions than municipal solid waste.

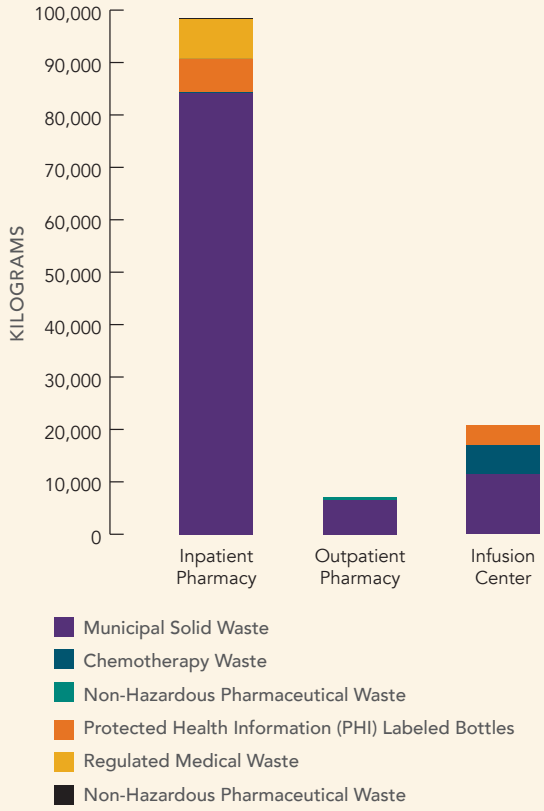
Processing of PHI waste, such as a prescription bottle with a patient's name on the label, also generates higher emissions because it requires longer transportation distances (to a limited number of waste processors) and more processing steps (usually shredding).

Higher volumes of certain waste materials create emissions hot spots because the heavier the weight, the greater the energy requirement for transporting and processing the material. Some materials have higher emissions profiles than others. Plastic generates higher emissions across its life cycle, compared to material such as cardboard, because plastic production involves an energy-intensive extraction process to obtain its raw ingredient (fossil fuels) and cardboard feedstocks (wood) are renewable carbon-sinks. Plastic can also cause significant pollution at the end of its lifecycle when it degrades into microplastics and through the release of toxins when incinerated. Glass has higher associated emissions because of the high heat required to produce it and because transporting it requires more energy due to its heavy weight.

Average Annual Greenhouse Gas Emissions, by Site, Production and Disposal



Annual Weight of Waste, by Site



Regulated medical waste generates disproportionately high emissions compared to other waste streams, but it could be dramatically reduced through better sorting

While RMW accounts for 4% of BMC's total waste by weight, averaging 300,000 to 400,000 pounds per year, it accounts for an outsized proportion of the cost at 25% of total waste management spending due to the extra processing required during disposal. Furthermore, it accounts for more than 30.5% of BMC's scope 3 waste emissions, again due to the additional processing steps.

The waste audits revealed that 75–85% of RMW was not correctly sorted and could have been disposed of in recycling and municipal solid waste streams. Improving the sorting rates offers a substantial opportunity to reduce emissions and create savings for the hospital. If the missorted waste were diverted from the RMW to the trash, the disposal cost would drop 89% per pound. Savings for the hospital can be redirected to patient care. Data from Health Care without Harm suggests that rates of RMW mis-sorting in other hospital areas (such as emergency departments) may be similar or even higher to what was observed at BMC, again demonstrating a major opportunity for scaling the RMW reduction innovations that this collaboration is designed to produce.

The most commonly missorted items (by weight) included glass vials or ampoules (12.1 kg per day), IV bags with and without tubing (6.2 kg per day), and syringes without needles (5 kg per day). These insights will directly inform behavioral change interventions to boost staff understanding of what constitutes RMW, as well as operational changes in waste management practices to reduce mis-sorting. Proper disposal of all missorted items that were discarded in RMW receptacles could lead to a 69% reduction of total RMW disposal emissions (from 20.2 kg CO_2e total disposal emissions per day to 2.9 kg CO_2e per day from RMW disposal).

Single-use plastics waste drives emissions from primary packaging waste

Across all sites, the most common primary drug packaging types were all single-use plastic items. Plastic waste accounted for 44% of audited waste and 63% of the GHG emissions (excluding tertiary packaging). The most common items were plastic caps from bottles, vials, or syringes (1,470 per day), followed by blister packs (808 per day), and syringes (734 per day).

The most common plastics subtypes (by weight) within the waste stream included:

- 13% low-density polyethylene, accounting for 19% of GHGs*
- 10% high-density polyethylene, accounting for 8% of GHGs
- 7% polyvinyl chloride, accounting for 11% of GHGs
- 6% polypropylene, accounting for 12% of GHGs
- 3% nitrile (gloves), accounting for 5% of GHGs

Of these, polypropylene and polyethylene are accepted by many recyclers, while polyvinyl chloride and nitrile are more difficult to recycle.

Plastic Waste by Type, All Sites

PLASTIC TYPE	ANNUAL WEIGHT, KG (ALL SITES)
Low Density Polyethylene (e.g. thin-film plastic)	7848
High Density Polyethylene (e.g. manufacturer pill bottles)	5621
Polyvinyl Chloride (IV bags and tubing)	4015
Hard Plastic Polypropylene Plastic (e.g. prescription pill bottles, syringes)	3650
Polypropylene Fabric (e.g. gowns and blue wrap)	2227
Nitrile Butadiene (gloves)	1862
Expanded Polystyrene (Styrofoam)	1132
Thermoplastic Rubber	365
Plastic Foam	146

*All weight-based percentages exclude tertiary packaging. Emissions percentages include both production and disposal-associated emissions.

Individual audit sites had unique waste and emissions hotspots

Among the three audit sites, the inpatient pharmacy was by far the largest source of waste and emissions. The inpatient pharmacy, which serves the inpatient units, operating rooms, and the emergency department, dispenses 10,000–11,000 prescriptions per day, an average of 19 per patient. Because of this high volume, the inpatient pharmacy produced more than four times as much waste by weight as the infusion center per day and more than twice the daily emissions. It produced 14 times more waste than the outpatient pharmacy by weight and more than 17 times the emissions.

Although many trends were common across the three audit sites, each location also had distinct waste hot spots. This means that future solutions will need to be tailored to each site, rather than a "one-size-fits-all" approach. The inpatient pharmacy generated far more trash can liners—11.8 kg per day—than any other site, making liners the second-largest source of emissions for that location, after tertiary packaging. The outpatient pharmacy produced 3.5 kg of paper per day, primarily drug inserts, which was substantially higher than other sites. The infusion center generated 3.5 kg of plastic nitrile gloves daily, also far more than other sites—an expected finding given the center's direct patient-care activities, where glove use is routinely required.

Tertiary packaging is a major contributor to both waste and emissions, particularly in the inpatient pharmacy. The inpatient pharmacy alone generates more than 65,853 kg of tertiary packaging each year—55,990 kg of corrugated cardboard and 9,863 kg of ice packs and insulation materials. Altogether, this results in an estimated 72,155 kg CO_2e of GHG emissions annually across the products' lifecycle. This is the equivalent of over 7.4 million gallons of gas burned per year.

Daily Weights and Greenhouse Gas Emissions by Material Type for All Audit Sites

PLASTIC WASTE									
	Plastic Gloves	Hard Plastic Polypropylene Plastic (orange pill bottles, syringes)	Thin Film Plastic Low Density Polyethylene	Polypropylene Plastic Fabric (blue wrap and gowns)	High Density Polyethylene (hard plastic pill bottles)	Polyvinyl Chloride Plastic (IV bags and tubing)	Plastic Rubber	Plastic Styrofoam	Soft Plastic Foam
Daily Weight (kg)	5.1	10.0	21.5	6.1	15.4	11.0	1.0	3.1	0.4
Production GHG Emissions ($kgCO_2e$)	23.0	47.0	82.0	25.3	31.3	41.8	4.0	21.8	2.6
Disposal GHG Emissions ($kgCO_2e$)	0.2	4.9	0.7	0.2	3.7	3.0	0.4	0.1	0.0

OTHER MATERIALS									
	Glass	Aluminum	Stainless Steel	Cotton/Fabric	Paper	Paper Towel	Paperboard	Cardboard	Ice Packs
Daily Weight (kg)	14.4	1.2	0.8	4.0	11.8	1.6	10.5	154.2	29.5
Production GHG Emissions ($kgCO_2e$)	15.5	1.8	4.5	34.8	12.0	4.8	9.8	197.1	1.8
Disposal GHG Emissions ($kgCO_2e$)	8.8	0.3	0.5	0.2	0.4	0.1	0.3	3.8	0.7

BMC and Takeda together will explore shifting to product packaging materials that produce lower emissions. Solutions may include reusable, biobased/biodegradable materials, or readily recyclable packaging and supplies. One potential solution to reduce emissions from prescription bottles is a paper-based prescription bottle, which recently became available on the market.

Intravenous (IV) bags and tubing are another significant driver of waste and emissions. Together, the infusion center and inpatient pharmacy dispose of over 4000 kg of polyvinyl chloride (PVC) IV bags and tubing annually, generating an estimated 16,425kg CO_2e across their lifecycle—equivalent to over 41 thousand miles driven by a gasoline-powered car.

Notably, 72% of IV bags discarded by the inpatient pharmacy were unused, an inefficiency that further increases emissions due to the additional weight of transporting full bags. PVC IV bags and tubing also contain Di(2-Ethylhexyl) Phthalate (DEHP), a known carcinogen that leaches into the medication contained in the bag. Even without DEHP, PVC is the most toxic of all plastics to human health, particularly in its production phase, and its chlorine content makes it nearly impossible to recycle.

The outpatient pharmacy purchases approximately 395,700 polypropylene prescription bottles each year. Most of these familiar orange bottles are discarded in patients' homes, with a smaller portion thrown away onsite. Across their lifecycle, these bottles generate an estimated 38,927 kg CO_2e, equivalent to over 99 thousand miles driven by a gas-powered car. The inpatient and outpatient pharmacies also discard an estimated 65,700 bulk pill bottles annually. These containers—white high-density polyethylene bottles used by manufacturers for pill-based medications—produce roughly 4,234 kg CO_2e each year across their lifecycle, equivalent to over 10 thousand miles driven by a gas-powered car.

Top 10 Primary Packaging Types by Quantity and Weight*

PRIMARY PACKAGING TYPE	WEIGHT PER DAY (KG)	QUANTITY PER DAY
IV Bag/Tubing	**29.7**	**279**
Glass Vial	**16.6**	**568**
Syringe	**10.4**	**734**
White Plastic Pill Bottle	**4.9**	**180**
Plastic Caps (for Syringes, Vials, Bottles, etc.)	**2.2**	**1470**
Blister pack	**1.7**	**808**
Polypropylene Orange Plastic Pill Bottle	**1.2**	**102**
Syringe Wrapper	**1.0**	**722**
Plastic Liquid Medication Bottle	**1.0**	**61**
Needle	**0.9**	**204**

*Any medication remaining inside packaging waste is included in the weight because the added weight contributes to disposal emissions.

Opportunities for targeted solutions

Analysis of the audit data showed that three factors were to blame for the hotspots we identified: disposal method, volume, and material type. These three areas will form the foundation on which we will build solutions. Diverting waste from high-emissions waste streams to less intensive ones will be a key strategy, as it creates value through both emissions reductions and cost savings. We will work to reduce waste volume by improving efficiency and increasing the use of reusable packaging and supplies. We can optimize material type by shifting to reusable or readily recyclable packaging and supplies.

RMW represents a major opportunity for both waste and emissions reduction. Improving proper waste sorting—through staff education, clearer signage, and strategic bin placement—could significantly reduce the volume of RMW generated in the pharmacies and infusion center. Diverting plastic pill bottle waste in the outpatient pharmacy from the PHI waste stream into recycling is another large opportunity, because PHI processing is twelve times more emissions intensive than recycling. PHI-containing labels could be removed from prescription bottles, which would allow the bottles to be recycled instead of processed as PHI.

The audit also revealed that IV bags are a major source of waste and emissions in the inpatient pharmacy, with 72% discarded unused. Here is a key opportunity to reduce volume. Many of these unused bags are thrown away due to inefficiencies in the compounding workflow; streamlining this process offers a direct opportunity to reduce waste at the source and achieve cost savings. For IV bags that still contain fluids even after workflow improvements, technologies are available that shred bags onsite, release retained liquid, and therefore lower emissions associated with hauling excess weight. The collaboration could also explore partnerships with IV packaging manufacturers to improve recyclability and reduce toxicity. For example, BMC could switch

to recyclable polypropylene IV bags, which are free of ortho-phthalates, a carcinogenic plasticizer found in most polyvinyl chloride IV bags.

Tertiary packaging—corrugated cardboard boxes and ice packs—was the largest category of waste across all three sites and the largest source of emissions. Even though BMC recycles all corrugated cardboard, the sheer volume drives emissions: 152 kg per day, representing 44% of the total daily waste generated across all three audit sites. Transporting such a high volume of material has a substantial carbon footprint. Switching to reusable shipping containers could substantially reduce both upstream and downstream emissions, as could a supplier take-back program for reusable ice packs. A transition to reusable shipping totes for pharmaceutical products would require coordinated action among suppliers and customers, and the Takeda/BMC collaboration is well positioned to explore this opportunity.

Although recycling can be less impactful than reducing or reusing, it will nevertheless be an important strategy in this collaboration because plastics play a critical role in drug safety, sterility, and patient care. Working with suppliers to increase recycled content in packaging can reduce production emissions, since recycled plastics have a lower carbon footprint than virgin materials derived from petrochemicals. Simplifying product designs—using fewer materials and additives—also improves recyclability. For instance, though not widely available, a 100% polypropylene blister pack would be fully recyclable in contrast with conventional mixed plastic-and-foil packaging. This collaboration can similarly explore circular solutions for hard plastic pill bottles and patient prescription bottles, including take-back programs and requiring higher recycled-content inputs. Advanced recyclers can also process nitrile gloves.

72%

discarded IV bags are unused

Key opportunities for the collaboration

Dr. Anna Goldman and Environmental Services leadership at Boston Medical Center prepare regulated medical waste for audit and collection. Cross-functional collaboration was critical to successful waste segregation and data collection.

A pharmacy tech disposes of expired medications in BMC's inpatient pharmacy.

Our work for the next two years

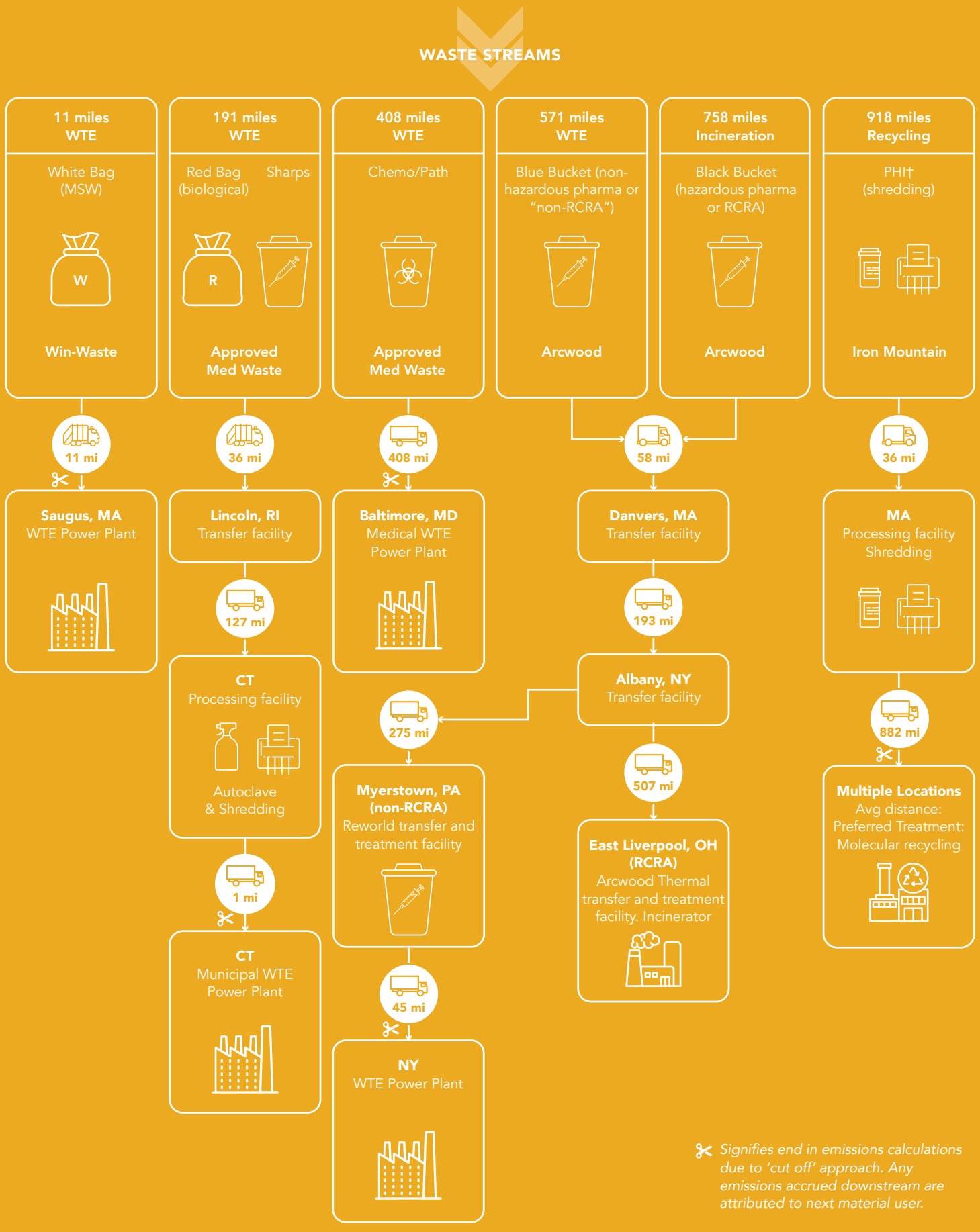
This report marks the completion of the first year of Takeda and BMC's collaboration. The year one audit uncovered multiple opportunities for near-, mid-, and long-term solutions to lower emissions, cut operational cost, and improve patient-care environments. The second year will focus on solution development, followed by the piloting of interventions in the third year. In the coming year, BMC and Takeda will engage internal and external stakeholders, subject matter experts, and peer organizations to share findings and gather feedback on proposed solutions. Solution design will be data-driven and iterative, with ongoing refinement to achieve meaningful reductions in waste volume, cost, and greenhouse gas emissions.

We anticipate developing a broad portfolio of solutions, all based on the conceptual framework that emerged from the audit process: diverting waste to less emissions-intensive disposal methods; reducing waste volume; and improved sustainability of materials. Some interventions will be straightforward and suitable for rapid implementation, such as strategic changes to RMW and PHI waste handling at BMC. Others will require more substantial investment, including modifications to primary drug packaging, changes to shipping practices, or changes in procurement.

These higher-effort initiatives have the potential to produce significant reductions in scope 3 emissions not just in hospitals like BMC, but across the health system value chain. To measure the impact of our efforts, we will collect pre- and post-implementation data to assess feasibility and quantify changes in waste generation, emissions, and cost.

The Takeda/BMC collaboration is intended to serve as an incubator for generating data-driven solutions that can be scaled across the broader healthcare ecosystem. A core goal of the partnership is to engage peer organizations—health systems, pharmaceutical manufacturers, and waste-management firms—to share learnings and to learn from their insights. This external engagement begins with the release of this report, which includes both BMC's waste audit results and the **Waste Audit Guide** to assist other organizations undertaking similar assessments. Engagement with external partners will continue throughout the solution development phase and expand during the third year, when we will invite collaborators to participate in piloting interventions. BMC and Takeda recognize that achieving meaningful reductions in GHG emissions requires collective action: developing effective solutions together and scaling them widely.

Figure 1: End-of-Life Disposal Pathways of BMC Waste Streams



✂ *Signifies end in emissions calculations due to 'cut off' approach. Any emissions accrued downstream are attributed to next material user.*

WTE: Waste to Energy

Boston Medical Center
HEALTH SYSTEM

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