Reusable Health Care Textiles for Use in Personal Protective Equipment: Proceedings of a Workshop (2024)

DETAILS

122 pages | 6 x 9 | PAPERBACK

ISBN 978-0-309-71884-4 | DOI 10.17226/27762

CONTRIBUTORS

Kelsey R. Babik, Tamara Haag, and Autumn Downey, Rapporteurs; Board on Health Sciences Policy; Health and Medicine Division; National Academies of Sciences, Engineering, and Medicine

SUGGESTED CITATION

National Academies of Sciences, Engineering, and Medicine. 2024. *Reusable Health Care Textiles for Use in Personal Protective Equipment: Proceedings of a Workshop*. Washington, DC: The National Academies Press. https://doi.org/10.17226/27762.

NATIONAL ACADEMIES *Sciences Engineering Medicine*

NATIONAL ACADEMIES PRESS
Washington, DC

Reusable Health Care Textiles for Use in Personal Protective Equipment

Kelsey R. Babik, Tamara Haag, and Autumn Downey, *Rapporteurs*

Board on Health Sciences Policy

Health and Medicine Division

Proceedings of a Workshop

NATIONAL ACADEMIES PRESS 500 Fifth Street, NW Washington, DC 20001

This activity was supported by a contract between the National Academy of Sciences and the Department of Health and Human Services (Contract 75D30121D11240/75D30123F00020). Any opinions, findings, conclusions, or recommendations expressed in this publication do not necessarily reflect the views of any organization or agency that provided support for the project.

International Standard Book Number-13: 978-0-309-71884-4
International Standard Book Number-10: 0-309-71884-8
Digital Object Identifier: https://doi.org/10.17226/27762

This publication is available from the National Academies Press, 500 Fifth Street, NW, Keck 360, Washington, DC 20001; (800) 624-6242 or (202) 334-3313; http://www.nap.edu.

Printed in the United States of America.

Suggested citation: National Academies of Sciences, Engineering, and Medicine. 2024. *Reusable health care textiles for use in personal protective equipment: Proceedings of a workshop*. Washington, DC: The National Academies Press. https://doi.org/10.17226/27762.

The **National Academy of Sciences** was established in 1863 by an Act of Congress, signed by President Lincoln, as a private, nongovernmental institution to advise the nation on issues related to science and technology. Members are elected by their peers for outstanding contributions to research. Dr. Marcia McNutt is president.

The **National Academy of Engineering** was established in 1964 under the charter of the National Academy of Sciences to bring the practices of engineering to advising the nation. Members are elected by their peers for extraordinary contributions to engineering. Dr. John L. Anderson is president.

The **National Academy of Medicine** (formerly the Institute of Medicine) was established in 1970 under the charter of the National Academy of Sciences to advise the nation on medical and health issues. Members are elected by their peers for distinguished contributions to medicine and health. Dr. Victor J. Dzau is president.

The three Academies work together as the **National Academies of Sciences, Engineering, and Medicine** to provide independent, objective analysis and advice to the nation and conduct other activities to solve complex problems and inform public policy decisions. The National Academies also encourage education and research, recognize outstanding contributions to knowledge, and increase public understanding in matters of science, engineering, and medicine.

Learn more about the National Academies of Sciences, Engineering, and Medicine at **www.nationalacademies.org**.

Consensus Study Reports published by the National Academies of Sciences, Engineering, and Medicine document the evidence-based consensus on the study's statement of task by an authoring committee of experts. Reports typically include findings, conclusions, and recommendations based on information gathered by the committee and the committee's deliberations. Each report has been subjected to a rigorous and independent peer-review process and it represents the position of the National Academies on the statement of task.

Proceedings published by the National Academies of Sciences, Engineering, and Medicine chronicle the presentations and discussions at a workshop, symposium, or other event convened by the National Academies. The statements and opinions contained in proceedings are those of the participants and are not endorsed by other participants, the planning committee, or the National Academies.

Rapid Expert Consultations published by the National Academies of Sciences, Engineering, and Medicine are authored by subject-matter experts on narrowly focused topics that can be supported by a body of evidence. The discussions contained in rapid expert consultations are considered those of the authors and do not contain policy recommendations. Rapid expert consultations are reviewed by the institution before release.

For information about other products and activities of the National Academies, please visit www.nationalacademies.org/about/whatwedo.

PLANNING COMMITTEE FOR A WORKSHOP ON REUSABLE HEALTH CARE TEXTILES FOR PERSONAL PROTECTIVE EQUIPMENT[1]

SUNDARESAN JAYARAMAN (*Chair*), Kolon Professor, School of Materials Science and Engineering, Georgia Institute of Technology
ELIZABETH L. BEAM, Associate Professor, University of Nebraska Medical Center College of Nursing
GAJANAN S. BHAT, Professor and Department Head, Textiles, Merchandising, and Interiors, University of Georgia
JACQUELINE A. DALEY, Senior Director, Infection Prevention, Providence St. Joseph Health, Irvine, California
MELISSA DAWSON, Associate Professor and Program Director of Industrial Design, Rochester Institute of Technology
ELIZABETH P. EASTER, Professor, University of Kentucky
NICOLE (NIKKI) V. McCULLOUGH, Vice President, Application Engineering and Regulatory, Personal Safety Division, 3M Company
BARBARA STRAIN, Principal, Barbara Strain Consulting, LLC
KELLY N. WRIGHT, Director, Division of Minimally Invasive Gynecologic Surgery, Associate Professor of Obstetrics and Gynecology, Cedars-Sinai Medical Center, Los Angeles, California

Health and Medicine Division Staff

AUTUMN DOWNEY, Senior Program Officer
KELSEY R. BABIK, Associate Program Officer
EMILY McDOWELL, Research Associate (*from June 2024*)
ASHLEY BOLOGNA, Senior Program Assistant
CLARE STROUD, Senior Director, Board on Health Sciences Policy

Consultants

LAURA RUNNELS, LARC Consulting, Workshop Facilitator
AMY SCHLOTTHAUER, LARC Consulting, Workshop Facilitator
TAMARA HAAG, Doxastic LLC, Science Writer
ANNA NICHOLSON, Doxastic LLC, Science Writer
BRIAN MacCREADY, Spark Street Digital, Webcast Producer

[1] The National Academies of Sciences, Engineering, and Medicine's planning committees are solely responsible for organizing the workshop, identifying topics, and choosing speakers. The responsibility for the published Proceedings of a Workshop rests with the workshop rapporteurs and the institution.

Reviewers

This Proceedings of a Workshop was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise. The purpose of this independent review is to provide candid and critical comments that will assist the National Academies of Sciences, Engineering, and Medicine in making each published proceedings as sound as possible and to ensure that it meets the institutional standards for quality, objectivity, evidence, and responsiveness to the charge. The review comments and draft manuscript remain confidential to protect the integrity of the process.

We thank the following individuals for their review of this proceedings:

SHELLEY PETROVSKIS, Lac-Mac, American Reusable Textile Association
JACQUELINE DALEY, Providence St. Joseph Health, Irvine, California

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the content of the proceedings nor did they see the final draft before its release. The review of this proceedings was overseen by **ELI Y. ADASHI,** Brown University. He was responsible for making certain that an independent examination of this proceedings was carried out in accordance with standards of the National Academies and that all review comments were carefully considered. Responsibility for the final content rests entirely with the rapporteurs and the National Academies.

We also thank staff member Stephen Maher for reading and providing helpful comments on this manuscript.

Acknowledgments

The National Academies' staff wish to express their gratitude to the National Institute for Occupational Safety and Health's National Personal Protective Technology Laboratory for sponsoring the workshop; to the speakers whose presentations and discussions helped inform workshop discussions on the challenges and opportunities related to disposable and reusable health care textiles for personal protective equipment; to the members of the planning committee for their work in developing the workshop agenda and shaping the discussions; and to additional National Academies staff and consultants, without whom this workshop and the accounting thereof would not have been possible: Christie Bell, Lori Brenig, Samantha Chao, Robert Day, Marguerite Romatelli, and Taryn Young.

Contents

Boxes, Figures, and Table

BOXES

FIGURES

TABLE

Acronyms and Abbreviations

AAMI	Association for the Advancement of Medical Instrumentation
AATCC	American Association of Textile Chemists and Colorists
AECS	Aravind Eye Care System
AHN	Allegheny Health Network
ALM	Association for Linen Management
ANSI	American National Standards Institute
ASTM	ASTM International (formerly American Society for Testing and Materials)
C. diff	*Clostridioides difficile*
CAUTI	catheter-associated urinary tract infection
CDC	Centers for Disease Control and Prevention
HHS	U.S. Department of Health and Human Services
ED	emergency department
EHMR	elastomeric half mask respirator
EPA	U.S. Environmental Protection Agency
ESF	European Safety Federation
EU	European Union
EVS	Environmental Services
FDA	U.S. Food and Drug Administration

GPO	group purchasing organization
HAI	health care-associated infection
HCTs	health care textiles
HCW	health care worker
HLAC	Healthcare Laundry Accreditation Council
ICU	intensive care unit
IFU	instructions for use
LCA	life-cycle analysis
NIOSH	National Institute for Occupational Safety and Health
NPPTL	National Personal Protective Technology Laboratory
NYU	New York University
OR	operating room
OSHA	Occupational Safety and Health Administration
PAPR	powered air-purifying respirator
PET	polyethylene terephthalate
PFAS	per- and polyfluoroalkyl substances
PLA	polylactic acid
PPE	personal protective equipment
PWFMC	Providence Willamette Falls Medical Center
RFID	radio-frequency identification
RPD	respiratory protective device
SHC	Stanford Health Care
TJC	The Joint Commission
TM	test method
TRSA	Textile Rental Services Association

1

Introduction[1]

Personal protective equipment (PPE) is a critical component of infection prevention and control strategies in health care settings. The COVID-19 pandemic revealed gaps in the ability of health care systems to ensure that health care workers (HCWs) have adequate access to PPE during times of surge in demand, placing both HCWs and patients at risk. In 2023, the U.S. Congress requested that the Department of Health and Human Services examine the feasibility and potential benefits of increased use of reusable health care textiles (HCTs) in medical settings to protect HCWs, address worsening environmental effects associated with disposable HCTs, prepare for future pandemics, and potentially provide cost savings (Landsman et al., 2023).

On March 4 and 5, 2024, the National Academies of Sciences, Engineering, and Medicine's (the National Academies') Board on Health Sciences Policy held a public workshop sponsored by the National Institute for Occupational Safety and Health's (NIOSH's) National Personal Protective Technology Laboratory (NPPTL) to convene technical experts, policy makers, manufacturers, PPE users, and other interested parties to identify opportunities to increase the use of reusable HCTs for PPE in health care

[1] The planning committee's role was limited to planning the workshop, and the Proceedings of a Workshop has been prepared by the workshop rapporteurs as a factual summary of what occurred at the workshop. Statements, recommendations, and opinions expressed are those of individual presenters and participants and are not necessarily endorsed or verified by the National Academies of Sciences, Engineering, and Medicine, and they should not be construed as reflecting any group consensus.

settings (see Box 1-1 for the Statement of Task for the workshop).[2] Adam Smith, senior scientist at NIOSH's NPPTL, described NPPTL's dedication to addressing all issues concerning PPE, including opportunities for supporting and sustaining the increased use of reusable PPE in health care settings. NPPTL sponsored this workshop to expand and understand a number of these issues through the exchange of knowledge and ideas among key value holders.

In designing the workshop, the planning committee considered various aspects involved in the safe and sustainable use of reusable HCTs in health care operations. Workshop topics include (1) risk assessment of the effects of reusable HCTs on patient and HCW safety; (2) characterizing and comparing the environmental risks and benefits associated with both reusable and disposable HCTs through use of a life-cycle analysis (LCA) approach; (3) economic analysis of increasing use of reusable HCTs, with a focus on short- and long-term infrastructure investments; (4) identification of elements of a decision-support framework to explore adopting more reusable HCTs in health care operations; and (5) potential implementation strategies and behavior change models to promote increased use of reusable HCTs. Through workshop presentations, case studies, discussions, and collaborative exchanges on each of these different topics, the planning committee sought to create opportunities to explore innovation, sustainability, regulatory considerations, and emerging trends related to reusable HCTs.

In his opening comments, Sundaresan Jayaraman, professor and director of the Kolon Center for Lifestyle Innovation at the Georgia Institute of Technology, defined the scope of reusable PPE as referring to products that are designed to be laundered or cleaned and reused under both standard and surge situations. He clarified that reusable PPE does not include the reprocessing of PPE designed for single use. Jayaraman noted that increasing the use of reusable HCTs for PPE requires balancing numerous factors because the safety of HCWs and patients is paramount and at the core of health care's purpose. Comprised of care, quality, and equitable protection, this safety must be ensured while considering aspects of reusable PPE related to environmental sustainability and potential economic savings, he stated.

[2] A recording of the full workshop can be found on the event's webpage: https://www.nationalacademies.org/event/41729_03-2024_reusable-health-care-textiles-for-personal-protective-equipment-a-workshop (accessed June 6, 2024).

BOX 1-1
Statement of Task

A planning committee of the National Academies of Sciences, Engineering, and Medicine will organize a public workshop to examine opportunities to increase the use of reusable health care textiles (HCTs) for personal protective equipment (PPE) used in health care settings. This workshop will provide the opportunity to exchange knowledge and ideas among key stakeholders—including technical experts, policy makers, manufacturers, and PPE users in health care—and to explore the potential benefits and feasibility of integrating more reusable HCTs into health care operations. The workshop will feature invited presentations and discussions to:

- Examine existing recommendations, approaches, and guidelines relating to reusable HCTs to ensure optimal protection of patients and health care workers;
- Discuss issues related to contamination of textiles and fabrics in health care facilities;
- Explore issues associated with current product and technology standards for reusable HCTs, considering input on standards needs from a past National Institute for Occupational Safety and Health (NIOSH) Personal Protective Technologies (PPT) Centers of Excellence Federal Register Notice;
- Examine the comparative performance, comfort, environmental impact, and use issues for disposable and reusable HCTs;
- Highlight similarities and differences between U.S. and European systems for reusable HCT use/maintenance/disposal systems, sustainability, and standards/regulations;
- Explore potential benefits, including potential cost savings, and feasibility issues related to increasing the use of reusable HCTs in crisis and everyday situations and in different health care settings;
- Discuss opportunities and approaches to integrate more reusable HCTs into health care operations where appropriate.

The planning committee will organize the workshop, develop the agenda, select and invite speakers and discussants, and moderate or identify moderators for the discussions. A proceedings of the presentations and discussions at the workshop will be prepared by a designated rapporteur in accordance with institutional guidelines.

ORGANIZATION OF THE PROCEEDINGS

This Proceedings of a Workshop summarizes the presentations and discussions that took place during the public workshop held on March 4 and 5, 2024. Chapter 2 provides a foundation of key terms and concepts related to reusable HCTs and describes current U.S. ecosystems for disposable and

reusable HCTs for PPE. Chapter 3 outlines current policies and standards that influence the ecosystems for disposable and reusable PPE. Chapter 4 characterizes the environmental risks and benefits associated with reusable versus disposable HCTs within health care settings using an LCA approach. Chapter 5 examines the economic implications of reusable versus disposable HCTs with a focus on short- and long-term infrastructure investments for health care facilities and value holders. Chapter 6 explores patient and HCW safety and PPE quality considerations associated with reusable HCTs using a risk-based assessment framework. Chapter 7 delves into the elements of a decision-support framework a health care organization might consider in exploring increased use of reusable HCTs in operations. Chapter 8 focuses on implementation strategies and systems, behavior change models, and barriers relevant to promoting the increased adoption of reusable HCTs. Chapter 9 provides a summary of the workshop, as well as reflections and next steps from the workshop sponsor. Appendix A contains the reference list. Appendix B includes a list of key terms and definitions, Appendix C contains the workshop agenda, and Appendix D includes brief biographies of planning committee members, speakers, and workshop staff.

2

Level Setting: The U.S. Ecosystem for PPE

The first session laid the foundation for the workshop by defining key terms and concepts and by describing current complex networks and interconnected systems (i.e., the ecosystems) involved in the manufacturing, distribution, use, and disposal of reusable and disposable health care textiles (HCTs) for personal protective equipment (PPE) in the United States. These ecosystems were introduced by session moderator Elizabeth Easter, professor at the University of Kentucky, who began by referring participants to a set of key terms in the workshop briefing materials, which are included in Appendix B. These definitions and descriptions were compiled to ensure a shared understanding of the ecosystem. In some cases, workshop speakers further clarified or expanded on the definitions. However, every effort was made to be consistent with existing definitions and descriptions from standards organizations and federal agencies. The workshop planning committee established isolation and surgical gowns as the primary HCTs for PPE that were the focus for the workshop. Additional clarification was provided to note that HCTs that are not PPE (e.g., patient gowns, surgical drapes) were not within the scope of the workshop. While they are not HCTs, reusable elastomeric respirators, which are a form of reusable PPE, were also a focus of discussions for the workshop.

Easter emphasized that health care workers (HCWs) include not only medical professionals, but all individuals working within a health care setting who use PPE in their daily tasks or who come into direct contact with health care PPE. Thus, "HCW" encompasses employees who collect, clean, or otherwise care for soiled PPE.

The PPE ecosystem is well established, robust, and entails major operations that begin with PPE design, manufacturing of raw materials, manufacturing of PPE, and distribution, Easter explained (see Figure 2-1). Next, the health care facility procures PPE, manages inventory and issuance, and utilizes PPE. Soiled PPE is collected and disposed of, laundered, or cleaned within the health care setting or at an external laundering facility. For reusable HCTs, laundering involves: (1) collecting and packing soiled items; (2) transporting the used HCTs to an in-house or external laundering department or facility; (3) receiving and laundering soiled HCTs; (4) testing laundered HCTs; (5) determining suitability for reuse; and (6) labeling, packing, and (where applicable) shipping laundered HCTs. The health care facility then receives, stores, and manages issuance of the laundered reusable HCTs. Standards, conformity assessment, and regulatory compliance apply to all operations of this ecosystem. Easter presented a video produced by the Textile Rental Services Association (TRSA) demonstrating the operations within a commercial laundry facility, including sorting soiled items, automated washing and drying, packing processes that ensure laundered HCTs remain clean, and sanitizing the carts that transported soiled HCTs.[1] She introduced the life-cycle analysis of HCTs, which considers the cost, energy, equipment, people, and time used in creating, distributing, using, reusing, and ultimately recycling or disposing of a product. This analysis also determines the environmental effects of each of these stages of a product's lifespan.

LIFE CYCLES OF TEXTILES USED FOR HEATH CARE PPE

John Wintz, group vice president at Standard Textile, provided an overview of reusable PPE manufacturing, processing, and end-user usage, focusing specifically on reusable medical gowns, including isolation and surgical gowns, that are used as PPE in health care settings. He also described regulatory requirements for the field, the evolution of reusable fabrics, and testing and tracking of reusable PPE. Charlie Merrow, chief executive officer at Merrow Manufacturing, compared and contrasted manufacturing processes for reusable and disposable HCTs.

Reusable HCT Life Cycle

The manufacturing of reusable medical gowns begins with development and extrusion of polyester filament yarns, said Wintz. The yarn is

[1] The clip shown during the workshop can be found on the workshop recording and the full video may be accessed at https://www.youtube.com/watch?v=kauTYYj7Rc8 (accessed March 14, 2024).

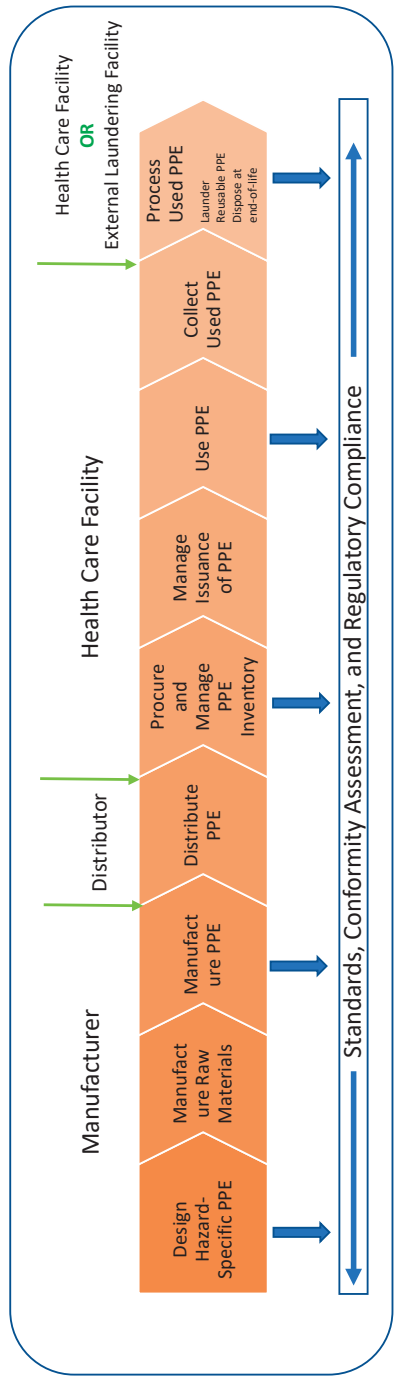

FIGURE 2-1 Major operations in the personal protective equipment ecosystem.
SOURCE: Presented by Elizabeth Easter on March 4, 2024, at the Reusable HCTs for PPE Workshop.

shipped to a manufacturing plant where it is woven into fabric that is either 100 percent polyester or 99 percent polyester and 1 percent electrostatic dissipative yarn. Fabric formation entails wet finishing, dyeing, quality assurance testing of barrier performance, and other measures.[2] Finished fabric is shipped to a cut-and-sew manufacturer that creates garments in a range of sizes with various closures. Isolation gowns typically use tape tie closures at the neck and waist, whereas surgical gowns feature a combination of snaps and tie closures. Additional quality assurance testing is conducted before products are delivered to health care settings or the laundry facilities that service them. In many cases, the reusable HCTs are purchased and owned by the laundry facility, not the hospitals using them, adding an additional level of oversight on the condition of the HCTs, as it is in the laundry facility's best interest to provide their health care clients with high-quality HCTs. Wintz noted that Standard Textile trains end users on proper donning and doffing procedures, which resemble those for disposable products aside from the location for placing soiled linens.

Reusable isolation gowns are laundered before initial use, and then the method for tracking the number of reuses is implemented, Wintz explained. Tracking can be performed via barcodes, radio-frequency identification (RFID) chips, or grid labels affixed to gowns that are manually marked with indelible marker. Gowns are then distributed to health care settings, and carts of bagged gowns are directed to appropriate departments. After using the gowns, HCWs place soiled gowns in laundry bags. The laundry facility processes and inspects the gowns, marking the tracking grid or scanning the RFID chip or barcode on each item. Depending on the model, reusable gowns generally have a lifespan of 75–100 uses. Laundered gowns that have not reached this limit are redistributed into circulation, whether that means they are sent to health care facilities serviced by a laundry or added back into a facility's supply by their on-site laundry. In cases where tracking indicates that a gown has reached the maximum number of uses specified, it is retired from service via donation, disposal in a landfill, repurposed in the health care system, or recycled. Wintz calculated that the average 500,000 isolation gowns that Standard Textile sells annually equate to 30–35 million uses if each gown is used 60–70 times.

[2] Barrier performance represents the level of protection afforded by a medical gown. This is determined by the performance of each area of the gown "where direct contact with blood, body fluids, and other potentially infectious materials is most likely to occur." Four levels of barrier performance are defined, with Level 1 being the lowest level of protection and Level 4 being the highest level of protection (ANSI/AAMI, 2022).

The ecosystem for surgical gowns is slightly more complicated, as it involves sterilization of surgical packs, said Wintz. Laundered surgical gowns are packed in a surgical packing area or facility and undergo 100 percent inspection (i.e., every item is individually inspected) over light tables, tracked, and sent to assembly, where they are folded using an aseptic technique. Wintz explained that these processes are conducted in adherence to the Association for the Advancement of Medical Instrumentation (AAMI) ST65 guidelines (ANSI/AAMI, 2018). Packs contain sterilization indicators that are read after the packs are steam sterilized and cooled. The sterilized surgical gowns are distributed to the operating room (OR), where they are used before undergoing the laundering and sterilization process once more.

Differences in Manufacturing of Reusable and Disposable HCTs

Following on Wintz's description of the reusable HCT life cycle, Merrow discussed key differences in the manufacturing processes for reusable and disposable medical gowns. The manufacturing of disposable HCTs is highly automated, often involving sonic welding[3] and other processes in lieu of sewing. Investment in the automation of disposable HCT manufacturing has been substantial. In contrast, reusable products are sewn, and the processes that craft them are similar to those used 20–30 years ago. The labor-intensive nature of reusable HCT manufacturing makes it more expensive than manufacturing disposable products. Additionally, reusable products are bulkier than disposable counterparts; therefore, the areas required to store and organize material before and after manufacturing vary from the layout of production facilities for disposables. Merrow highlighted an opportunity within the reusable HCT industry to update manufacturing processes and incorporate tracking technology to increase reusable HCT functionality and real-world application. While tracking is often performed by manually marking a tag with a permanent marker, incorporating RFID technologies into more reusable HCT products would improve tracking accuracy in the field. Furthermore, investment in automation could make it possible for products to be registered as they are manufactured, tracked throughout their lifespans, and measured again at disposal for a closed tracking loop. Innovation in PPE could enable reusable HCTs to be made from recycled materials, and the gowns themselves could then be recycled once reaching the end of the product's lifespan. A similar path toward sustainability does not exist for disposable polyethylene products, Merrow contended.

[3] Sonic Welding is a manufacturing process that can join textile parts by using high-frequency vibration to melt material at the junction of the parts (Micus et al., 2021).

Scaling of reusable HCTs is markedly different from that of disposable HCTs, said Merrow. Automated manufacturing of disposable medical gowns and masks scales with capital investment, whereas reusable HCTs scale with labor investment, which entails workforce training. Thus, an organization can scale manufacturing of a disposable product line more quickly than a reusable product line. Scaling requires investment, coordination, and demand. Increased automation of reusable PPE manufacturing would increase scalability, but the current demand for reusable PPE, particularly for reusable HCTs, is inadequate to motivate investment in automation, Merrow explained. He noted that the COVID-19 pandemic substantially increased demand for reusable PPE, spurring investment and scaling in this industry for the first time in two decades. Matching the scaling capacity of the disposable market within the reusable HCT industry would require replacing humans with robots. Developing the technology required for robots to sew HCTs is a 2- or 3-year process. Eventually, innovation could enable reusable PPE to be produced with processes that minimize environmental effects, lower prices, and enhance scaling capacity. Merrow stated that incorporation of existing technology could lower the cost of manufacturing, improve sustainability, and track reusable PPE throughout the life cycle within 3 years, given investment in implementation. Wintz remarked that robotics and highly efficient machinery are currently being used to increase the efficiency with which reusable HCTs are manufactured, and this innovation has resulted in decreased prices for reusable products.

Evolution of Fabric for Barriers

Over time, fabrics used as barriers have evolved to attain higher levels of performance, Wintz explained. The first generation of these fabrics were 100 percent cotton and featured low thread count, large pore sizes that increased with each processing, and lint generation. Furthermore, these fabrics were not resistant to liquids. The 1960s saw the introduction and growth of disposable fabrics with barrier resistance claims. In the 1970s, the industry began to shift toward the use of blended fabrics, incorporating 45–50 percent polyester with cotton to decrease the fabric's pore size. However, pores continued to increase in size with each processing, lint generation remained high, and fabrics were not liquid resistant. Treating fabric with barrier chemicals originally developed for military uniforms achieved liquid resistance. A chemically treated, 100-percent-cotton iteration featured a higher thread count to decrease pore size. Yet, the cleaning and sterilization processes abraded the cotton, and liquid resistance decreased as the chemical barrier degraded. The 1980s ushered in the current generation of barrier fabrics, which contain 100 percent polyester

multifilament yarns that provide a high level of consistent and reliable liquid resistance. These fabrics are virtually lint free, easily processed, cost-efficient, and comfortable to wear. Meeting all flame-spread restrictions and requirements, this generation of fabrics is breathable, allowing body heat to evaporate while maintaining a barrier against liquids. Wintz shared his optimism about the future of reusable fabrics as barriers, given the technology fueling development of new synthetic yarns that will be hydrophobic, and compactable to tighten pore size and will feature a permanent liquid-resistant finish that is free of per- and polyfluoroalkyl substances (PFAS). Moreover, potential exists for the development of biodegradable 100 percent synthetic yarns.

Medical Gown Requirements

While policies and standards for medical gowns were the focus of a later session, high-level discussions were held to provide context regarding medical gown requirements. Wintz outlined the U.S. Food and Drug Administration (FDA) requirements for isolation gowns and surgical gowns, which are classified as Class I and Class II medical devices, respectively. Isolation gowns are typically AAMI Level 1 or 2, with Level 1 gowns constituting 95 percent of isolation gowns sold by Standard Textile. FDA requires that manufacturing of Class I devices takes place in a facility that adheres to the quality system regulation and is registered with the FDA.[4] Surgical gowns range from AAMI Levels 1 through 4, and the majority of OR gowns are Level 3, said Wintz. In addition to meeting the requirements for isolation gowns, surgical gowns are subject to a higher level of scrutiny as Class II medical devices. Surgical gowns require 510(k) premarket submission to FDA to demonstrate that at the end of life (i.e., after a maximum number of cleaning and sterilizing cycles defined by the manufacturer) the device remains safe and effective in continuing to meet regulations regarding barrier performance, flammability standards, lint generation, and other metrics.[5]

Shipments of gowns are required to include instructions for use, which is a common requirement for health care industry supplies, Wintz noted. The instructions for reusable medical gowns specify indications for use, processing procedures, sterilization procedures, patching and mending criteria, application of fabric patches, guidelines for inspection, life use tracking, and recommendations for barrier performance

[4] Quality System Regulation, 21 CFR Part 820 (October 7, 1996).

[5] More information about Premarket Notification 510(k) is available at https://www.fda.gov/medical-devices/premarket-submissions-selecting-and-preparing-correct-submission/premarket-notification-510k (accessed March 16, 2024).

testing throughout the life of the product. Required safety and efficacy tests assess fluid barrier performance, flammability, durability through 75 cleaning and sterilizing processes, strength, lint generation, toxicity, and compatibility with steam sterilization. Guidance from AAMI PB70 indicates specific standardized testing to determine performance level and assign ranked classification (ANSI/AAMI, 2022).

SUSTAINABILITY IN THE PPE INDUSTRY

Dan Glucksman, senior director for policy at the International Safety Equipment Association (ISEA), discussed market drivers of sustainability, sustainable practices in the PPE industry, and anticipated trends in the field. In addition to providing PPE manufacturers with a forum in which to develop standards, ISEA offers policy advocacy, insight into the PPE market, and education for customer-facing safety professionals that includes documentation of completed training via Occupational Safety and Health Administration (OSHA) 30 cards, proof of completing an OSHA-approved occupational health and safety training session. The U.S. PPE industry employs 130,000 people in manufacturing, distributing, and selling PPE, with PPE protecting 125 million workers, said Glucksman. The largest PPE needs are hand protection and safety apparel, used by 105 million and 102 million workers, respectively.

Market Drivers of Sustainability

Glucksman described growing market forces that drive sustainability and reflect growth in consumer products with environmental, social, and governance claims such as electric cars and energy-efficient household appliances. A consumer survey found that 60 percent of individuals are willing to pay more for a product with sustainable packaging (Feber et al., 2023). Sustainability efforts are increasing within the business sector, with 80 percent of surveyed business leaders viewing sustainability as helping to optimize and reduce costs and 86 percent seeing sustainability as an investment that protects against disruption (Gartner Inc., 2022). A survey of PPE suppliers found that 96 percent of respondents employ some sustainable business practices, and 70 percent of PPE manufacturers consider sustainability commitments important to their overall competitiveness (ISEA, 2023b). Furthermore, 68 percent of 370 hospitals surveyed have a sustainability procurement policy in place (Practice Greenhealth, 2023). Examples of sustainability efforts include PPE manufacturer Ansell's substantial investment in sustainable packaging and provision of an environmental impact calculator to users. Thermal Compaction Group, a sustainable solutions company in the United Kingdom, converts dispos-

able face coverings into blocks of raw polypropylene that can be used to make products ranging from toolboxes to lawn chairs (Pigott, 2021). Glucksman noted that regulatory factors are also in play. For instance, in 2022 the U.S. Securities and Exchange Commission (SEC) proposed rules requiring listed companies to disclose greenhouse gas emissions for all material suppliers, transportation of materials, and manufacturing sites.[6] Notwithstanding the high cost that compliance with this proposed regulation could carry, SEC recommended these rules in response to investor demand for useful, comparable, and reliable information. Additionally, a 2021 executive order from the Biden administration requires federal agencies to adopt various sustainability practices.[7]

Sustainability Trends in PPE Industry Practices

Glucksman highlighted a 2023 ISEA member survey that benchmarked current sustainability practices, assessed customer and stakeholder engagement, and predicted future trends (ISEA, 2023a). He noted that most ISEA members are mid-sized manufacturers. The survey found that 86 percent of respondents employ sustainable business practices related to product packaging. Furthermore, a majority of those surveyed use sustainable industry practices related to product materials and design (66 percent), operations and facilities (60 percent), and the supply chain (55 percent). Respondents cited regulatory compliance as the primary driver for sustainable practices, followed by new growth opportunities and alignment with company values and mission. Glucksman associated new growth opportunities with customer demand for sustainable products, citing one respondent's feedback that "it's critical to our mission and our customer base to be more sustainable than the industry." Indeed, 87 percent of companies surveyed identified end-user pressure as an important driver of sustainability decisions. Even so, end users often do not want to pay a premium for sustainable products, and less than 10 percent of respondents indicated that end users are "very likely" to be willing to pay a premium for products that help meet environmental, social, and governance goals. "It's all about trade-offs. Most everyone wants sustainability, but they don't want the production cost increases required to pay for it," a survey respondent commented. Nonetheless, 77 percent of companies surveyed consider sustainability an important

[6] The SEC adopted these rules on March 6, 2024, after the conclusion of the workshop: The Enhancement and Standardization of Climate-Related Disclosures for Investors, 17 CFR Parts 210, 229, 230, 232, 239, and 249 (March 6, 2024).

[7] Executive Order 14057: Catalyzing clean energy industries and jobs through federal sustainability (December 8, 2021).

driver of competitiveness, and 89 percent expect sustainability practices to become a more important purchase criterion in the next 3 years.

Currently, some companies are using sustainability as a differentiator, and Glucksman predicted that this trend would grow to the point that only companies with some level of sustainability in their operations have a chance of remaining competitive in the market. Customer preferences for inclusive and fashionable PPE are also driving business trends. The market is responding to increased demand for PPE that fits all body shapes, sizes, and genders. Moreover, users want PPE that is stylish and fits properly. Glucksman remarked that ISEA members strive to be responsive to these needs and are actively participating in developing solutions at the interface of manufacturing and customer preferences.

REUSABLE PPE CONSIDERATIONS IN HEALTH CARE

Pamela Falk, epidemiologist at the Association for Professionals in Infection Control and Epidemiology, outlined requirements for PPE in various medical contexts, current literature on reusable HCTs, and considerations regarding PPE inventory management, laundering, storage, and waste. She noted that use of PPE, such as gloves and gowns, became more widespread in health care in the 1980s during the acquired immunodeficiency syndrome epidemic to protect HCWs from exposure to blood and body fluids, and subsequently, potential exposure to infection from the human immunodeficiency virus and viral hepatitis. Use of PPE in health care has continued to expand, and gowns, gloves, and masks are routinely used by HCWs to protect themselves from infection and to diminish the transmission of infectious agents between patients, such as those placed in isolation.

PPE Considerations for Various Health Care Contexts

The health care setting informs PPE needs, as various types of PPE are required for the OR, endoscopy laboratory, patient rooms, isolation rooms for infectious diseases, and inpatient and outpatient areas. Falk asserted that the variability in PPE manufacturing and use across health care contexts precludes a one-step solution to PPE waste in health care. For example, PPE worn in trauma surgery ORs is required to be sterile and impermeable to body fluids. Surgeons often press their bodies against the surgical field, and they therefore need protection from exposure to blood and body fluid seepage. She noted that HCW exposure to the blood or body fluids from a patient with an infectious blood-borne disease may require post-exposure prophylaxis medication depending on the situation. Blood and body fluids passing through PPE (i.e., strikethrough) can

also harm the patient, as any blood transferred from the operative field to the surgeon's skin could carry bacteria from the surgeon's skin into the patient's wound, creating risk for infection. Thus, surgical gown strike-through is a breach in sterile technique, Falk explained.

All gowns worn in the OR must be sterile, but standards differ for various types of procedures and services in health care settings, said Falk. For instance, gowns worn for ophthalmology or other surgeries that involve low levels of blood or body fluid spillage don't require the same level of impermeability as gowns used in surgeries with greater potential fluid transfer. Procedures performed outside of the OR, such as some endoscopy, urology, and ear, nose, and throat procedures, require gowns that guard against fluid transfer but do not always necessitate sterile gowns. The gowns worn by HCWs while giving patients baths must protect against soap, water, and body fluids, as baths may expose HCWs to feces, urine, and, in some cases, blood. In contrast, when dietary workers deliver meals to patients in isolation with multidrug-resistant microbial infections, no level of impermeability is required in gowns. However, the risk of transmitting infectious agents from one patient to another necessitates that gowns are worn as a barrier between the HCW and the environment. Before leaving a patient's room, the dietary worker would need to remove and dispose of the gown to prevent germs from being carried into other areas of the hospital. Falk emphasized that the invisible nature of infectious agents makes it challenging to recognize the hazard they present on gowns that appear to be clean. The variety of needs stemming from diverse health care procedures and services requires an array of PPE.

Data Considerations

Given the variety of PPE purposes, Falk underscored the importance of stratifying PPE by use when generating data and conducting analyses on types of exposures in health care. An analysis that includes both PPE for bathing a patient and PPE for trauma surgery could give rise to confusing conclusions. Yet, much of the data currently available on PPE fail to make the distinction between sterile and non-sterile settings, she asserted. For example, a literature review examining PPE permeability might aggregate various gowns without stratifying data according to context, such as setting (e.g., OR) or procedure (e.g., endoscopy, meal delivery, or patient bathing). Therefore, conclusions based on non-stratified data may be confounding. Sterility and permeability requirements for given contexts should be considered and similar products compared in conducting PPE analyses, said Falk.

Logistics

Numerous factors must be considered in storing, laundering, and disposing of PPE, noted Falk. Chief among these factors is storage, as space is often a resource in short supply. Most hospitals do not have warehouses or material management areas, and on-unit space is prioritized for patient care. Given these space constraints, many hospitals use just-in-time inventory management, a strategy that involves keeping minimal inventory on hand and timing product delivery shortly before use. Packaged disposable gowns are more compact than their reusable counterparts, requiring less space for storage. Storage space for soiled linens and waste is also limited, and surgical gowns containing blood and body fluids may be considered biohazardous, thus requiring specialized, secure storage. Some large hospitals have autoclaves on-site that sterilize and shred biohazardous waste before sending it to a landfill.

An additional logistical consideration relates to product availability. The range of sizes, shapes, and styles of disposable gowns is currently wider than for reusables, although the reusable HCT industry is working to narrow this gap.

Laundering presents several logistical considerations highlighted by Falk. Reusable gown wash cycles must be tracked to ensure that the PPE continues to offer adequate protection. Reusable gowns contaminated with large amounts of blood can be difficult to wash. Workers in laundry facilities must wear PPE when sorting soiled reusable HCTs, generating additional laundry. Laundry facilities use chemicals and produce wastewater, and these environmental considerations should be considered. Most laundry facilities found in nursing homes and hospitals lack the capacity to sterilize gowns. Falk concluded that PPE waste can be reduced, but the complete elimination of disposable PPE is unlikely.

DISCUSSION

Tracking Reusable PPE Lifespan and Product Loss

In response to a question about the use of tracking to prevent product loss and ensure that PPE is not used beyond the established lifespan, Merrow stated that the technologies for improved tracking currently exist; manufacturers and hospital systems could organize an approach to using these technologies in a manner aligned with their goals. Wintz noted that RFID and barcode chips enable monitoring of both product usage and disappearance and that these tracking methods are currently used more often than manual marking. Each time a product is washed, a worker scans the RFID or barcode chip, and the electronic reader issues an alert

when a product reaches its maximum lifespan. Reusable PPE is clean at the time of tracking; thus, products sent to landfills, recycling, or donation programs are clean. In conducting cost analyses, Wintz reduces the number of uses from 75–100 to 55–65 to provide a conservative estimate that accounts for potential product loss or damage.

Reusable PPE and PFAS

A workshop participant asked if the elimination of PFAS chemicals—which demonstrate excellent water repellency and have therefore been used in PPE manufacturing to provide barrier resistance to liquids—affects the lifespan of reusable PPE. Wintz remarked that there are over 20,000 chemicals containing PFAS. Standard Textile does not manufacture products or have any surgical or isolation gowns containing PFAS or perfluorooctanoic acid and is working toward PFAS-free facilities within the next few years. Eliminating PFAS does not change the performance characteristics of HCTs in terms of lifespan, said Wintz. He added that Standard Textile is currently testing its PFAS-free products in accordance with FDA 510(k) filings. Easter stated that she has been involved in testing several varieties of PFAS-free gowns, and performance continued to meet the standards through 75 washes and, in some cases, up to 200 washes. Products free of PFAS are currently coming onto the market in the PPE arena. Wintz noted that for some types of reusable PPE, eliminating PFAS chemicals is not expected to increase manufacturing or consumer cost.

Demand for Reusables During the COVID-19 Pandemic

A question from the audience focused on buyer demand for reusable PPE during the COVID-19 pandemic. Merrow recounted that in situations where both disposable and reusable PPE were available, almost all hospitals chose disposable products, both for cash flow purposes and for standard practices within hospital systems. Hospitals tend to maintain as small an inventory of PPE as possible, and switching from disposable to reusable products requires a larger initial outlay. Supply shortages led 121 hospitals to purchase reusable PPE from Merrow Manufacturing, all of which returned to disposable products once they became available. In fall 2020, Merrow Manufacturing achieved price parity (the price level that sets two items equal in value to one another) between imported single-use disposable products and amortized reusable PPE, even when accounting for laundering costs, yet the preference for disposable PPE persisted, Merrow emphasized. This indicates that the hesitancy to adopt reusable products cannot solely be attributed to cost considerations, Merrow said. Wintz remarked that Standard Textile saw a similar trajectory. He linked

the preference for disposable PPE to familiarity and ease of use rather than an in-depth cost analysis, as costs are competitive. Notwithstanding this preference, Standard Textile—one of several U.S. manufacturers in the industry—sells approximately 500,000 reusable PPE products each year.

Innovation and User Engagement to Foster Adoption of Reusable PPE

In response to a question about design innovations that could increase HCW engagement in transitioning from disposable to reusable PPE, Merrow emphasized the value of soliciting and incorporating user feedback in designing, iterating, and improving PPE. He remarked that PPE is used in thousands of environments that feature subtle differences. Merrow Manufacturing incorporated input from health care providers in creating a reusable gown prototype crafted from 100 percent recycled product that could withstand 200 wash cycles. He highlighted a tremendous opportunity to improve fiber, fabric, and design to optimize sustainability and fitness to application. Wintz reiterated the opportunity for innovation within reusable PPE, including efforts to advance recyclable yarns to establish cradle-to-cradle, closed-loop systems in which HCT products at the end of their lifespan could be recycled into new products. He also expects further innovation in robotics for manufacturing reusable PPE. Efforts are needed to increase demand for reusable products and Wintz was optimistic that the current amplification of sustainability messaging generally taking place will foster demand for reusable PPE. He noted that increased use of reusable PPE will improve sustainability even if the use of disposables is not eliminated. Falk stated that many hospitals and nursing homes convene product evaluation committees to test technologies as they enter the market. Members of these committees use and evaluate newly available PPE in their work settings. This process is a mechanism for educating HCWs about products and generating buy-in. Falk added that an organization might engender resistance in pushing out an unfamiliar product to all employees simultaneously, particularly for products relied upon for safety.

3

Level Setting: Policies and Standards for PPE

The second session of the workshop described current policies and standards that influence the ecosystems for disposable and reusable personal protective equipment (PPE). Elizabeth Beam, associate professor at the University of Nebraska Medical Center College of Nursing, introduced and moderated the session. She clarified that the session's focus on standards and policies governing everyday use of PPE does not extend to crisis standards or to policies pertinent to emergency use authorization. The session featured standards and policies relevant to all major operations of the PPE ecosystem. Beam referenced the key terminology and definitions included in the workshop briefing materials (see Appendix B) and key standards for surgical and isolation gowns and noted their inclusion on PPE packaging (see Table 3-1).

POLICIES AND STANDARDS FOR MANUFACTURERS

PPE Manufacturing Standards

Jeffrey Stull, president at International Personal Protection and member of the Committee on Standards for Medical Face Masks and Protective Clothing at ASTM International (ASTM), provided an overview of medical gown standards and requirements for U.S. Food and Drug Administration (FDA) clearance. Three prominent consensus standards apply to medical gowns. Updated in 2022, the American National Standards Institute (ANSI)/Advancement of Medical Instrumentation (AAMI) standard PB70:2022 sets barrier requirements for gowns used for isolation and

TABLE 3-1 Key Standards for Surgical and Isolation Gowns

Purpose	Description	Test Method (TM)	Test Name	Parameters Evaluated	Passing Metrics
AAMI Level 1	Used for MINIMAL-risk situations. *Example*: basic care	AATCC TM42	Test Method for Water Resistance: Impact Penetration	Minimal water resistance (some resistance to water spray)	≤ 4.5 g
AAMI Level 2	Used in LOW-risk situations. *Example*: vein blood draws, pathology labs	AATCC TM42	Test Method for Water Resistance: Impact Penetration	Low water resistance (resistance to water spray)	≤ 1.0 g
		AATCC TM127	Test Method for Water Resistance: Hydrostatic Pressure		≥ 20 cm
AAMI Level 3	Used for MODERATE-risk situations. *Example*: arterial blood draws, ER/trauma departments	AATCC TM42	Test Method for Water Resistance: Impact Penetration	Moderate water resistance (resistance to water spray)	≤ 1.0 g
		AATCC TM127	Test Method for Water Resistance: Hydrostatic Pressure		≥ 50 cm
AAMI Level 4	Used for HIGH-risk situations. *Example*: pathogen and infectious disease (non-aerosolized)	ASTM F1670	Standard Test Method for Resistance of Materials Used in Protective Clothing to Penetration by Synthetic Blood	Blood and viral penetration resistance	Pass (at 2 psi)
		ASTM F1671	Standard Test Method for Resistance of Materials Used in Protective Clothing to Penetration by Blood-Borne Pathogens Using Phi-X174 Bacteriophage Penetration as a Test System		Pass (at 2 psi)

Laundering	Laundering	ANSI/AAMI ST65:2000	Processing of Reusable Surgical Textiles for Use in Health Care Facilities	• Design criteria for all applicable work areas • Staff qualifications • Transporting, receiving, handling, storage • Laundry processing (loading, washing, drying) • Inspection, testing, and maintenance of laundered textiles • Preparation and packaging of laundered textiles • Installation, operation, care, maintenance of laundry equipment • Quality control measures, procedures, and practices • Medical device regulatory considerations

SOURCES: Presented by Elizabeth Beam on March 4, 2024, at the Reusable HCTs for PPE Workshop (AATCC, 1945, 1968; ANSI/AAMI, 2018; ASTM, 1995a,b).

surgical purposes (ANSI/AAMI, 2022). The recent revision broadened the previous version to cover additional types of medical apparel that traditionally were not effectively covered by the standard, such as togas and hoods. In addition, ASTM established ASTM F2407/F2407M-23a, a standard that applies to surgical gowns, and ASTM F3352/F3352M-23b, a standard for isolation gowns (ASTM, 2006, 2019). These standards reference ANSI/AAMI PB70:2022, include additional mandatory or optional properties, and specify a conformity assessment program, said Stull (ANSI/AAMI, 2022).

Medical Gown Performance Testing

Stull explained that ANSI/AAMI PB70:2022 sets an acceptable quality limit (AQL) of 4 percent to demonstrate barrier classification for four Classification Levels.[1] Each level has varying barrier criteria: Level 1 offers impact resistance and features the lowest level of protection; Levels 2 and 3 meet barrier criteria for both impact resistance and hydrostatic pressure; and Level 4 provides viral penetration resistance for the highest level of protection. The AQL provides a statistical basis for establishing confidence that materials and seams will perform at the specified level. The ASTM standards provide further criteria that include biocompatibility—a characteristic sought for all medical devices—as well as sterility assurance, flame spread, tensile strength, tear strength, and seam strength. Moreover, manufacturers can opt to undertake testing methods for additional properties related to comfort, durability, and lint generation. Stull remarked that the ANSI/AAMI and ASTM standards offer a comprehensive pathway for specifying protective clothing properties for health care settings.

FDA Regulatory Oversight

Stull outlined specific PPE regulations pertaining to medical devices.[2] The regulations differentiate between non-surgical and surgical apparel, which are categorized as Class I and Class II medical devices, respectively. Class I devices are subject to general controls that include registration and listing with FDA, as well as appropriate labeling, recordkeeping, and good manufacturing practice to prevent misbranding or misrepresentation. The FDA requirements for Class II medical devices—which include surgical gowns—are more rigorous. In addition to the general controls in place for Class I, special controls apply to Class II devices. Primary among these

[1] An acceptable quality limit specifies the maximum allowable percentage of nonconformities detected during sampling inspection (ANSI/AAMI, 2022).

[2] *Code of Federal Regulations,* Title 21, Section 878.4040 Surgical apparel.

is the 510(k) process that involves provision of safety and efficacy data and demonstration that the product is comparable to a medical device previously cleared by FDA. In 2015, FDA issued guidance on premarket notification requirements for medical gowns (FDA, 2015), and during the COVID-19 pandemic, FDA provided enforcement guidance for gowns and other medical apparel (FDA, 2020).

The number of reusable gowns that have cleared FDA requirements reflects the challenges this process entails, said Stull. Since 2004, 13 reusable surgical gowns have received FDA clearance, yet only two of these have been cleared since 2010. In contrast, over 30 disposable surgical gowns received FDA clearance in 2022 alone. Compliance expenses are substantial, with an annual fee of $7,653 for FDA registration/listing and a one-time fee of $21,760 for the 510(k) application process. The product testing required to demonstrate that three non-consecutive lots meet the 4 percent AQL pose additional costs to the manufacturer. Stull remarked that some criteria are unclear—for example, there is an expectation that whole gowns be tested, but that does not align with some of the test methods. He added that current criteria do not adequately address the effectiveness of cleaning processes.

Additional Standards-Related Resources

Stull continued that in addition to the standards for PPE manufacturing, AAMI ST65 guidelines outline requirements for processing reusable surgical textiles, including gowns, after use (ANSI/AAMI, 2018). Moreover, AAMI published a guide for designing, testing, and labeling reusable medical devices, but Stull cautioned that this guidance principally applies to hard-surface products (AAMI, 2023). However, provisions for using artificial soiling to demonstrate adequate removal of those soils via appropriate laundering methods can apply to textile products.

Stull summarized that robust standards and guidelines are currently in place for medical gowns and related apparel. These standards feature specific provisions regarding how manufacturers evaluate, represent, and qualify gowns and include details related to reusable gowns, such as tracking number of uses. FDA provides oversight and establishes two tiers for gowns: general controls for non-surgical gowns—principally isolation gowns—and more complex processes applied to surgical gowns. Although guidance documents assist manufacturers in demonstrating standards, there are gaps for demonstrating cleaning process efficacy, Stull maintained.

Reusable HCTs for PPE Manufacturing Standards

Erika Simmons, technical director at the American Association of Textile Chemists and Colorists (AATCC), a professional textile association, reviewed AATCC international standards for medical textiles and outlined standards considerations for reusable HCTs. The association provides educational content and testing support products (e.g., equipment, reference materials) to aid in the performance of AATCC standards and procedures. In addition, the association conducts test method training for AATCC, ASTM, and the International Organization for Standardization (ISO). Furthermore, AATCC is an international standards organization that creates standards to help textile producers and brands measure product performance. These standards provide a consistent, repeatable means of textile evaluation that can be used worldwide (AATCC, 2024). Simmons highlighted the association's efforts to respond to emerging industry needs, as evidenced during the COVID-19 pandemic with the creation and approval of guidelines for general-purpose textile face coverings, which were conducted in less than a year (AATCC, 2020).

Compliant with World Trade Organization transparency guidelines, AATCC standards are created and vetted by industry experts, said Simmons. These standards are consensus-based and statistically validated to provide reproducible, data-driven results, neutral objectivity, and accessibility. She maintained that AATCC standards are preferable to internal and in-house test methods due to their ability to test, validate, and confirm the performance of textiles at multiple points throughout the process pipeline. AATCC works directly with other industry standards organizations to support the global testing community. Additionally, standards outside of the textile industry reference AATCC standards. For example, ANSI/AAMI PB70:2022 includes AATCC Test Method (TM) 42 and AATCC TM127 as methods of determining liquid barrier protection classification Levels 1-3 (AATCC, 1945, 1968). Applicable to any textile fabric, AATCC TM42 tests water resistance against impact penetration; therefore, it can be used to predict the resistance of fabrics to liquid penetration. This method involves applying liquid to a textile backed by blotting paper and then measuring the blotting paper to detect any change. Simmons highlighted that the specifications for the blotting paper required by ANSI/AAMI PB70:2022 differ from those for testing non-PPE textiles under AATCC TM42. For this reason, PPE testing should follow section 5.2 of ANSI/AAMI PB70:2022. Similarly, AATCC TM127 tests water resistance to hydrostatic pressure in any type of fabric (AATCC, 1968). Thus, when measuring the pressure required to push liquid through the health care textile (HCT), testing should follow ANSI/AAMI PB70:2022.

Specific Standards for Reusable HCTs

To meet the ANSI/AAMI PB70:2022 standard, reusable HCTs must demonstrate barrier performance at the end of a product's use life. Stull explained that this involves testing barrier performance after a product has undergone the number of laundering and/or sterilization processes indicated by the product's labeled use life. The standard stipulates that reusable PPE products must denote the number of times the product can be processed and include instructions for processing and for inspecting garments to ensure continued serviceability. The product design must feature an integral tracking mechanism—such as a grid for manual marking, RFID chip, or barcode—that remains functional throughout the labeled use life. He noted that although the use life of reusable gowns is often 75 washes, products have cleared the FDA requirements at up to 125 laundering cycles. In addition to barrier performance specified in the ANSI/AAMI standard, the ASTM F2407/F2407M-23a and ASTM F3352/F3352M-23b standards require physical properties testing after one laundering and sterilization cycle and again after the number of cycles indicated by the product's use life. The ASTM standards mirror the ANSI/AAMI standards in terms of requirements for the product design and technical information, added Stull, and they stipulate that labels include a use-by date.

Additional Standards Considerations for Reusable HCTs

In addition to water resistance, several functional and static considerations should be taken into account for reusable PPE, said Simmons. For instance, antimicrobial testing may be a predictive assessment of a product's life-cycle performance. Applicable antimicrobial tests include the AATCC TM147 and AATCC TM90, which measure antibacterial activity via the parallel streak and the agar plate method, respectively (AATCC, 1976, 1958). Antifungal activity against mildew and rot can be tested using TM30 (AATCC, 1946). The TM100 assesses antibacterial finishes, while the TM211 tests the reduction of bacterial odor on antibacterial-treated textiles (AATCC, 1961, 2021a). Although PPE is designed to provide safety, the visual condition of a reused garment should be considered, because it could affect the wearer's self-assurance and client perception of an organization's competence. For example, HCTs that exhibit stains or faded colors may convey negative impressions of the overall cleanliness and competence of the organization. Conducting colorfastness tests can contribute to maintaining a polished appearance. Colorfastness tests include the accelerated TM61 standard and tests for colorfastness to perspiration (TM15), colorfastness to water spotting (TM104), and colorfastness to

water (TM107) (AATCC, 1950, 1949, 1962a, b). Simmons noted that shrinkage performance reflects fitness and durability. Dimensional stability tests include the accelerated TM187 test and the TM135 and TM150 tests for home laundering (AATCC, 2000, 1970, 1977). These home laundering tests are designed to provide an accurate measure of a garment's true shrinkage potential and therefore can be applied to commercially laundered textiles.

Simmons emphasized that sustainability is a growing metric in the value chain, and TM212 assesses fiber fragment release during laundering (AATCC, 2021b). Fiber fragment shedding contributes to microplastic pollution, and TM212 was the first published global standard addressing the quantification of fiber fragment release, she noted. Textile producers continually investigate fabric-level solutions to shedding such as changes in finishes, yarn selection, or finished construction. Manufacturers can use TM212 to inform determinations of whether such process changes reduce fiber fragment release. Moreover, the international availability of this global standard facilitates comparison of results between locations throughout the supply line.

POLICIES AND GUIDANCE FOR USE

Federal Perspective

Lynne Sehulster, retired health scientist at the Centers for Disease Control and Prevention (CDC) Division of Healthcare Quality Promotion, outlined CDC guidelines for PPE and U.S. laundry industry standards for HCTs. She explained that various federal agencies are tasked with developing and issuing recommendations for infection prevention within health care. While some agencies under the umbrella of the U.S. Department of Health and Human Services (HHS) are regulatory, CDC focuses on the collection and distribution of applied research and, in some cases, partners with international groups such as the World Health Organization. The Healthcare Infection Control Practices Advisory Committee (HICPAC) provides advice and guidance to HHS and CDC on various aspects of infection prevention for hospitals and other health care facilities. Sehulster noted that the HICPAC guidelines most relevant to reusable HCTs are associated with isolation and infection prevention within specific settings in a health care facility.

CDC Guidelines for Health Care PPE

The 2007 version of the CDC isolation guideline (Siegel et al., 2007), which contains recommendations for the selection and use of PPE, was updated in part in 2023, said Sehulster. This isolation guideline includes

some indications of the proper use, purpose, and settings for PPE garments that apply to reusable HCTs. However, information regarding the processing of reusable PPE is absent from the isolation guideline; it is also missing from the guideline on management of multidrug-resistant organisms and the guideline on surgical sites. Sehulster remarked that CDC has multiple guidelines on preventing transmission of infectious disease, but only the isolation guideline specifies donning and doffing procedures. She added that the isolation guideline is due for updating, with release expected in 2024, but she could not confirm whether the updated version will address transporting, laundering, and sterilizing soiled reusable PPE. A CDC summary of core infection prevention practices within health care settings offers those new to the health care profession an introduction to controlling infectious disease (CDC, 2022); Sehulster proposed that health care settings make this information available to staff.

The National Institute for Occupational Safety and Health (NIOSH), an agency within CDC, is responsible for testing PPE for function, including the ability to prevent fluids and infectious material from penetrating through protective garments. Sehulster noted that NIOSH provides benchmarks for measuring the prevention of fluids from passing through fabric barriers and includes references to standards from AAMI, ASTM, and—for companies based in Europe—ISO (NIOSH, 2020).

Laundry Industry Standards

Sehulster outlined laundry industry standards recognized in the United States. These include the Healthcare Laundry Accreditation Council (HLAC) *Accreditation Standards for Processing Reusable Textiles for Use in Healthcare Facilities*, the Textile Rental Services Association (TRSA) Hygienically Clean Healthcare *Standard for Producing Hygienically Clean Reusable Textiles for Use in the Healthcare Industry*, and the Hohenstein *Hygienically Clean for Healthcare Textile Laundry Management* standard (HLAC, 2023; Hohenstein Laboratories, 2024; TRSA, 2021). Each set of standards is based on guidelines set by CDC and in some cases exceed what CDC has outlined. These industry standards specify all aspects of the laundry process needed to deliver clean HCTs to customers as well as the state of the built environment of the facility. Currently, the entities that issued these standards are conducting microbial testing of various fabrics and garments. Sehulster noted that ANSI/AAMI ST65 and PB70 also apply to laundered HCTs.

Health Care Perspective

Tiffany Wiksten, associate director of the Standards Interpretation Group at The Joint Commission (TJC), discussed TJC's approach to assess-

ing compliance with infection prevention and control and TJC requirements pertaining to PPE, laundering processes, and contracted services. While working with health care organizations, TJC strives to lead efforts to achieve excellence in sustainability and to collectively reduce the health care carbon footprint. Reusable PPE products offer numerous benefits, including cost-effectiveness, comfort, and a small environmental footprint. Wiksten noted that in selecting and employing PPE, health care organizations must (1) choose products that protect their staff from hazards that may be present where they perform their job duties; (2) develop policies, processes, and protocols to ensure proper PPE use and handling; and (3) ensure that reusable PPE products are reprocessed correctly to be safe for reuse and to function as designed.

Assessing Compliance with Infection Prevention and Control Requirements

TJC's approach to assessing compliance with infection prevention and control requirements is a framework developed in 2019 to aid organizations in prioritizing available sources of information for decision making regarding product choice and policy development processes and procedures, Wiksten explained. The framework outlines a process that begins with rules and regulations. When applying the framework to reusable PPE, this tier involves FDA requirements for medical device manufacturers to develop validated instructions for reprocessing. Such instructions may include indications for how an item should be laundered or dried, chemicals that can or cannot be used during laundering, methods of drying that retain PPE's fluid-resistant properties, the maximum number of reprocessing cycles, and instructions for sterilization if appropriate. Other pertinent rules and regulations include the Occupational Safety and Health Administration (OSHA) standards for bloodborne pathogens and PPE, including respiratory protection (OSHA, 2019a,b). Wiksten noted that regulations from the U.S. Environmental Protection Agency and from state administrative codes and state hospital licensing authorities may also apply.

The framework's second tier includes requirements of the Centers for Medicare & Medicaid Services that organizations develop policies, processes, and procedures that incorporate nationally recognized standards, said Wiksten. The third tier involves adherence to the manufacturer's instructions for use, which are developed in accordance with FDA requirements as outlined above. The fourth tier refers to evidence-based guidelines and national standards, and the fifth tier involves consensus documents. She explained that the resources used at the fourth and fifth tiers are at the organization's discretion, except in cases where an applicable state health care administrative code stipulates a specific evidence-based guideline, national standard, or consensus document, such as those

provided by CDC or the Association for Linen Management. The last level of the framework is the organization's infection prevention and control processes, policies, and protocols, which cannot be less restrictive than those outlined in the preceding tiers. However, an organization's processes, policies, or protocols may be more restrictive than those detailed by other requirements; Wiksten clarified that in these cases, employees must adhere to the organization's requirements.

PPE Evaluation Survey Elements

Numerous elements are evaluated during the TJC survey process, noted Wiksten. For instance, the survey team may assess adherence to the OSHA exposure control plan by determining whether an organization has conducted an annual assessment of risk to staff and follows the organization's written PPE program guidelines. According to these guidelines, the PPE program should identify PPE appropriate for various activities that may require different levels of fluid resistance and different types of PPE (e.g., gowns, gloves, eye protection, face shields). Appropriate PPE should be made available to staff in accordance with anticipated occupational exposure, with consideration of whether standard precautions or transmission-based precautions are warranted. Additionally, PPE should be available in sizes that fit all health care workers (HCWs) and in the locations where it will be used. Wiksten highlighted that survey elements apply to both disposable and reusable PPE. The survey process also assesses employee training. Employees should understand why specific types of PPE should be used and be competent in choosing appropriate PPE. Furthermore, employees should be trained on proper procedures to don, doff, and discard or disinfect PPE. Wiksten emphasized that reusable PPE necessitates an additional procedural step of placing soiled reusable PPE in a specified location. Use of PPE must be enforced via monitoring and providing feedback to staff. As issues are identified, action should be taken to address the issues and improve proper PPE use.

Laundering Processes Evaluation Survey Elements

In outlining elements of the TJC survey process used to evaluate laundering processes, Wiksten differentiated between organizations with in-house laundry facilities and those that contract laundering services. In assessing laundry facilities within an organization, the surveyor may check for availability of manufacturer's instructions for use and of all supplies and products required to complete laundering reprocessing of reusable PPE. A process should be in place for monitoring the number of times an item has been laundered and then removing items from ser-

vice after they have reached their maximum life cycle. Surveyors evaluate management of soiled linens through all phases, beginning with the point of use, followed by transport to the in-house laundry facility, and through a complete laundering cycle. Manufacturer's instructions for use should be followed for all steps of the processes for washing, drying, inspection, monitoring life-cycle use, storage, and transportation. Laundry facility employees should be competent in inspecting PPE for holes or tears, ensuring that PPE is suitable for reprocessing, and in carrying out laundering processes. Staff who oversee the laundering process should be competent in evaluating it, while leadership should provide oversight and hold staff accountable. Wiksten noted that surveyors also assess whether a process is in place to audit adherence to policies, process, and procedures.

Organizations that contract laundering services have responsibilities related to ensuring that reusable PPE meets standards, said Wiksten. A health care organization should describe, in writing, the nature and scope of services provided through contractual agreements. An organization's leaders should establish expectations for the performance of contracted services and communicate these in writing to the service provider. Leaders should monitor contracted services and evaluate them in relation to the organization's expectations. Lastly, leaders should take steps to improve contracted services that do not meet expectations. For example, if the health care organization receives items with holes or items not properly laundered, the leaders should give feedback to the third-party service providers, said Wiksten.

Laundry Services Provider Perspective

Liz Remillong, division vice president at Crothall Healthcare (now Core Linen Services), described commercial medical laundry technology, processes, standards, and trends over time. She noted that Core Linen Services processes various types of reusable HCTs, including patient care linens, scrubs, lab coats, and surgical linens (e.g., towels, wrappers, gowns).

Evolution of HCT Laundering Services

Health care laundry facilities have evolved substantially in recent decades, said Remillong. Historically, larger hospitals typically featured on-premises laundry facilities. Over time, hospitals shifted toward contracted services through central commercial laundry facilities. Scale varies at commercial laundries, with facilities ranging from 30,000 to 300,000 square feet in size and capable of processing laundry in annual quantities of 10–100 million pounds or higher. Technology has evolved

from traditional open-pocket washers to more sophisticated machines that use less water, electricity, and gas, thereby increasing environmental sustainability. Automation has reduced the number of touches required by laundry staff, enabling high consistency in wash and finish in producing hygienically clean HCTs. Furthermore, improvements in washroom chemistry over recent years have increased efficiency, thereby decreasing the time, temperatures, and energy required to produce hygienically clean loads. Past processes used up to 6 gallons of water per pound of laundry; current processes require less than half a gallon per pound. Remillong highlighted that given these decreases in water, electricity, and gas usage, the laundry industry has reduced its environmental footprint.

Ensuring Safety in Laundered Reusable PPE

Numerous steps are in place to ensure that laundered reusable PPE continues to provide necessary protection to HCWs, Remillong noted. Tracking via RFID technology not only indicates how many washes an item has been through within its life cycle but also works with internal laundry software to provide the location of PPE and length of time at that location. This technology can determine how long PPE has been stored on a shelf since laundering and provide documentation for customers or infection prevention personnel. She emphasized that the HLAC and TRSA Hygienically Clean standards have increased the level of sophistication in providing hygienically clean HCTs and, through third-party testing, demonstrating consistent service provision (HLAC, 2023; TRSA, 2021). Prior to the publication of these guidelines, which contain hundreds of standards, laundry facilities lacked HCT processing guidance specific to the industry. Remillong described how Core Linen Services operates under universal precautions with the assumption that all incoming items are heavily soiled with biohazardous waste. Therefore, all staff who receive linen are scrubbed, gowned, masked, and vaccinated, while all items are processed with the chemistry required to produce hygienically clean HCTs. Core Linen Services works closely with chemical providers to ensure that chemistry, temperature, and finishing are correct for the specific products received. Commercial laundry facilities that process PPE have on-site testing areas to ensure that water resistance and pressure testing standards are met.

Current Trends in Reusable PPE

Over the past two decades, demand for laundering reusable HCTs has decreased as the demand for disposable PPE has increased, said Remillong. The COVID-19 pandemic created a tremendous effect on demand, increasing

the number of reusable PPE products processed daily by 100- to 1,000-fold. Core Linen Services worked to link textile manufacturers with health care systems that, in turn, used their processing services. The PPE supply shortage was such that health care systems searched for any U.S. manufacturers able to provide their staff with products to keep them safe. Core Linen Services works with industry associations and with chemical and textile manufacturers to develop best practices both for typical business conditions and for crisis situations. Emergency preparation related to reusable PPE involves storage and processing capability in addition to processes documented by accreditation and certifications to provide safe and hygienically clean products for health care staff. Remillong emphasized that reusable PPE offers a consistent, cost-effective, environmentally preferrable method of keeping staff safe from occupational exposure to biohazards.

COMPARISON OF U.S. AND INTERNATIONAL POLICIES AND STANDARDS

Henk Vanhoutte, secretary general at the European Safety Federation (ESF), provided an overview of European Union (EU) PPE-related legislation and standards. As a trade association of PPE manufacturers, importers, and distributors, ESF provides guidance to support the provision of certified, high-quality PPE. EU Regulation 2016/425 contains requirements for PPE manufacturers and suppliers.[3] He noted that the EU defines PPE as equipment designed and manufactured to be worn or held by a person for the protection of his health and safety; this definition may be narrower than that within the United States. EU medical device legislation pertains to devices designed to protect the patient rather than the wearer. In the EU, both PPE and medical devices have essential requirements and are linked to conformity assessment procedures and to CE marking.[4]

Vanhoutte said that standards translate general requirements from legislation into practical requirements with test methods. Because of the risk of exposure to harmful biological agents and possibly chemicals in health care settings, the EU categorizes PPE in the highest risk category, Category III. Therefore, conformity assessment procedures for PPE involve examination by a third party. In contrast, most non-sterile medical devices are categorized as Class I, the lowest risk class, because these devices typically do not have invasive contact with patients. Con-

[3] *Regulation (EU) 2016/425 of the European Parliament and of the Council of 9 March 2016 on Personal Protective Equipment and Repealing Council Directive 89/686/EEC.*

[4] An acronym for the French "Conformite Europeenne" certifies that a product has met EU health, safety, and environmental requirements, which ensure consumer safety. Manufacturers in the EU and abroad must meet CE marking requirements where applicable in order to market their products in Europe (International Trade Adminstration, n.d.).

formity assessment procedures for Class I medical devices do not involve a third party. However, the quality of the sterilization process for sterile medical devices is subject to third-party conformity assessment testing. He used the example of masks and respirators to illustrate differences in classification. Filtering facepiece respirators worn to protect the wearer are categorized as PPE Category III, whereas surgical masks with the primary function of protecting the patient are Class I. Although the conformity assessment is less stringent for Class I medical devices than for Category III PPE, some requirements for medical devices are stricter than those for PPE. For example, all products and economic operators of medical devices must be registered. Vanhoutte added that PPE is subject to legislation regarding overall occupational health and safety that is based on risk analysis. Employers are required to provide appropriate PPE—in accordance with occupational risk analysis—free of charge to employees. Furthermore, employers are responsible for appropriate PPE maintenance and for training employees on the correct use of PPE products. In turn, employees are obligated to use the PPE.

Standards in Europe are designed to be technology-neutral and user-neutral, said Vanhoutte. This signifies that legislation for protection against infectious agents applies to health care, the pharmaceutical industry, the food industry, and all other industries. Moreover, the standards apply regardless of the technology employed, meaning that the same requirements apply to disposable and reusable PPE. For the latter, manufacturers must provide information on the proper maintenance and disinfection procedures, tests to apply, and the maximum number of washing cycles in a product's use life. Thus, if a manufacturer claims that a reusable PPE garment has a life cycle of 100 uses, they must indicate the exact decontamination procedure and prove that the product continues to offer consistent protection through 100 decontamination processes. Vanhoutte remarked that the COVID-19 pandemic increased the demand for products that simultaneously protect both the wearer and the patient; thus, efforts are underway to standardize products that function both as PPE and as medical devices. He added that in the context of sustainability, the European Green Deal and the Green and Digital Transformation of the EU are policies that have substantial effects on products and on users.[5]

[5] More information about the European Green Deal is available at https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en (accessed March 26, 2024). More information about the Green and Digital Transformation of the EU is available at https://digital-strategy.ec.europa.eu/en/news/eu-countries-commit-leading-green-digital-transformation (accessed March 26, 2024).

DISCUSSION

Restrictions on Toxic Substances in HCTs

Noting growing concern among HCWs regarding toxic exposure from PPE, Beam asked about whether any standards are in place regarding toxic substances in HCTs, such as phthalates, bisphenol A, or bisphenol S used to achieve color fastness or other desired properties. Stull replied that specific standards are in place for each type of toxic substance. Restricted-substance lists contain banned and restricted chemicals such as PFAS, phthalates, and heavy metals. Several organizations set limits for restricted substances. For example, the OEKO-TEX® Association created the OEKO-TEX Standard 100 to certify that garments pass safety tests for the presence of harmful substances.[6] Stull added that these harmful substances number in the hundreds, and OEKO-TEX updates specific limit values for these substances on an annual basis. Vanhoutte noted that the EU Registration, Evaluation, Authorisation, and Restriction of Chemicals regulation restricts manufacture and import of substances on a list that includes phthalates and some PFAS. This regulation ensures that toxic substances are not allowed in the manufacturing of PPE or medical devices, he added.

Disposable and Reusable PPE Testing

Beam asked whether differences apply within PPE standards with respect to test procedures or minimum required values in disposable versus reusable PPE. Stull explained that the performance criteria are the same for both types of PPE. A major difference in the application of ANSI/AAMI and ASTM surgical and isolation gown standards to disposable and reusable products is that the tests are also performed on reusable products after being processed to the maximum number of washing and sterilization cycles claimed by the manufacturer. He remarked that one would reasonably expect reusable products to be more robust than disposable PPE, but current standards do not account for higher physical property performance levels for reusable garments as compared to disposable products.

[6] More information about the OEKO-TEX Standard 100 is available at https://www.oeko-tex.com/en/our-standards/oeko-tex-standard-100 (accessed March 26, 2024).

Cost Associated with Reusable PPE Testing

Given that reusability testing can be expensive, Beam asked about steps that FDA could undertake to facilitate the manufacturing of reusable products versus single-use items. Stull replied that when he last cleared a reusable gown through FDA's process in 2010, ambiguity in demonstrating soiling cleanliness (as opposed to microbial cleanliness or sterilization) was a challenge. The process involves testing for carbohydrates, proteins, and blood matter, but there is no agreed-upon protocol specific to textiles. The expectation that manufacturers conduct this expensive testing may inhibit entry into the reusable product market, said Stull.

Requirements for In-House PPE Laundering

Beam asked whether there are procedures, such as inspections, that can enable a nursing home without access to a commercial laundry facility to launder PPE in-house in accordance with requirements. Wiksten stated that a nursing home would have to meet the minimum requirements specified in any applicable state regulation for laundering HCTs. Remillong added that in addition to meeting state requirements, a nursing home would need to follow the recommended process specified by the manufacturer. Any PPE classified above Level 1 is subject to requirements for additional testing. She remarked that both the HLAC and TRSA Hygienically Clean standards involve arduous processes, hundreds of specific standards, and independent inspections. To obtain accreditation, a nursing home would first need to meet the standards and then prove that standards are met by sending samples to a third-party laboratory for biotesting. Remillong emphasized that this thorough process ensures that standards are met and that the procedures involved in meeting the standards yield a hygienically clean product.

4

Environmental Impact

The third session of the workshop examined the environmental effects of increased adoption of reusable health care textiles (HCTs) within health care settings. These effects, including risks and benefits, were discussed within the context of life-cycle analysis (LCA). The session highlighted differences in U.S. and international policies, practices, and reusable HCT adoption rates. Kelly Wright, director of the Division of Minimally Invasive Gynecological Surgery and associate professor at Cedars-Sinai Medical Center, moderated the session.

ENVIRONMENTAL IMPACTS ACROSS THE LIFE CYCLE

Michael Overcash, chief executive officer at Environmental Genome Initiative, outlined benefits of reusable versus disposable medical gowns—such as increased sustainability and cost savings—in a presentation developed in collaboration with Jodi Sherman, associate professor and director of the Program on Health Care Environmental Sustainability at Yale University. Overcash stated that harms stemming from the mechanical world, the chemical world, and human behavior are inevitable. Given this context, the goal of "zero harm" is inherently challenging, making risk management a more practical goal (Thomas, 2020). Managing risk entails (1) understanding and identifying causal chains of events that lead to harm, (2) prescribing interventions to prevent harm, (3) tracking safety events, (4) measuring compliance with prevention protocols, and (5) ensuring accountability. Managing health care–related risk should involve exploring the complexities of the health care system to identify

health care factors that influence a given problem. Overcash noted that government and business leaders are seeking to provide quality personal protective equipment (PPE) while achieving the objectives of causing the least harm to the environment and lowering costs. He noted that literature is uniform in indicating that reusable PPE meets these objectives, while single-use PPE does not. However, barriers in the U.S. health care system impede the adoption of reusable PPE.

Reusable Gown Supply Chain and Environmental Footprint

Overcash described the reusable gown supply chain, which begins with natural resources used to make HCTs, such as the petroleum used to make polyester, a material commonly used for surgical and isolation gowns. A complicated process to create polyester involves building and improving molecular structures through chemical reactions until achieving terephthalic acid and ethylene glycol, which together form polyethylene terephthalate (PET), or polyester. The polyester is formed into pellets, a working material that can then be used to make fibers. These fibers are then manufactured into a variety of colors of yarn and woven into polyester fabric. Reusable gowns are manufactured from fabric and carbon thread, which is used for its anti-static properties. The gowns are packed into cardboard boxes or other types of packaging—all of which are manufactured via separate supply chains—and transported to commercial laundry facilities. Once laundered, the gowns are sent to hospitals, where they are used and then returned to the laundry facility for reprocessing. Laundering uses municipal water and expels wastewater to water treatment plants. The gowns are cycled between health care use and laundering until they reach the end of their use life, at which point they are typically sent to the landfill. Overcash noted that reusable gowns average 60 uses, thus 1,000 uses require 16.7 gowns. Given that reusable gowns can be used repeatedly, one reusable gown replaces 57 disposable gowns, said Overcash. Thus, reusable gowns create a smaller environmental footprint than disposables despite the complex supply chain involved in the manufacturing, transporting, and reprocessing of reusable gowns. Overcash emphasized that pursuing alternatives to disposable products that cause less harm to the environment is a worthwhile endeavor.

An ancillary benefit of the reusable gown supply chain is the recovery of items inadvertently discarded with soiled gowns, said Overcash. Recovered items include surgical instruments, trays, and pans as well as personal items such as cell phones, jewelry, and wedding rings. When laundry facilities recover these items, they decontaminate them and return them to hospitals. He highlighted that one laundry facility estimated the total value of items recovered each month at $5,000–15,000. In health care

settings using disposable gowns, these items would unwittingly be sent to the landfill among the disposable gown waste.

Environmental and Cost Savings Associated with Reusable HCTs

Overcash has collaborated on research measuring the reduced environmental effects or "environmental savings" of various types of reusable HCTs compared with disposable counterparts. They found that employing reusable surgical gowns in place of disposable gowns decreases greenhouse gas emissions by 66 percent (Vozzola et al., 2020). Conversely, the choice to use disposable gowns increases the global warming potential associated with gowns by 300 percent. Disposable gowns also generate more solid waste, blue water consumption, and natural resource energy consumption than reusable options (Vozzola et al., 2018a,b, 2020).

Overcash stated that growing evidence demonstrates that reusable HCTs for PPE improve environmental indicators, including reduced carbon emissions, water usage, solid waste, and energy consumption. The COVID-19 pandemic illustrated that the circular reusable PPE system is more stable than the linear disposable PPE supply chain. Despite these benefits, reusable HCTs constitute a small portion of the U.S. PPE supply. Group purchasing organizations (GPO) represent numerous health care providers and aggregate purchasing volume to negotiate price discounts with manufacturers and distributors. Overcash remarked that GPOs are more likely to contract for goods (e.g., disposable gowns) than for services (e.g., laundering services for reusable gowns). Thus, he concluded that achieving increased use of reusable PPE will involve addressing the barrier of GPO support for single-use products versus circular laundry services. Increasing circularity in systems through reusing and recycling drives environmental improvement.

A CASE STUDY OF ENVIRONMENTAL SUSTAINABILITY IN CLINICAL CARE

James Marvel, clinical assistant professor at the Stanford University School of Medicine, discussed the impetus for the reusable gown pilot program underway at Stanford Health Care (SHC) and explored implementation barriers. He described his interest in health care sustainability stemming from his fellowship in wilderness medicine and the health effects connected to climate change, particularly those related to the severe California wildfire seasons in recent years. Treating patients in the emergency department (ED) and discharging them to return to an environment that is potentially deleterious for their health inspired him to investigate ways to mitigate the effects of the health care system on the

environment. During the onset of the COVID-19 pandemic, he witnessed the surge of demand for isolation gowns. At that time, SHC was solely using disposable gowns, and the PPE supply challenges during the pandemic generated interest in exploring reusable HCTs. For a brief period, the SHC ED used reusable gowns, but this effort was a stopgap measure that did not involve a comprehensive plan for continuation. A group of Stanford University undergraduates and medical students advocated for the implementation of reusable gowns and coordinated with the university's Office of Sustainability to develop a plan.

Shifts from using disposable products to reusable ones generate cost and environmental savings, said Marvel. Disposable PPE carries additional environmental cost when unnecessarily treated as biohazardous waste. Marvel clarified that disposable gowns soiled with body fluids or other contaminants are biohazards. However, when health care workers (HCWs) doff PPE, they often do not consider whether it has been contaminated and routinely place all disposable PPE in the biohazardous waste bin. Because biohazardous waste must be processed by an autoclave before going to the landfill, health care facilities lacking an in-house autoclave must transport biohazardous waste to a separate facility for processing. Thus, processing disposable gowns as biohazardous waste can unnecessarily increase energy expenditures, Marvel noted.

To increase sustainability at the SHC ED, Marvel and colleagues established the ED Green Team. Various SHC departments use green teams to propose and implement sustainability initiatives (e.g., recycling, reprocessing, and redistributing pulse oximeters). The ED Green Team selected implementation of reusable gowns as its flagship project, a complex effort requiring consideration of numerous barriers. For example, the logistics of using reusable gowns involves locating space for the storage of both clean and soiled gowns, said Marvel. Reusable gowns are bulkier than their disposable counterparts, requiring cabinet storage space and laundry bins within patient rooms. Additionally, because SHC has a cache of disposable gowns, the ED Green Team has worked to align the timing of reusable gown implementation with depletion of the disposable gown supply. Reusable gown attrition is another logistical challenge. Given the complexity of the reusable gown supply chain and the volume of resources per unit compared to disposable gowns, a gown must be used a certain number of times to recoup its cost; reusable gowns lost before the break-even point result in a net loss. The ED Green Team identified a slight attrition rate of reusable linens at SHC, resulting in the need to periodically reorder linens sooner than expected. In exploring this issue, the team discovered an agreement in place with other area hospitals that allows emergency medical services staff to restock their ambulance gurneys with hospital linens.

To address potential staff resistance to change, the ED Green Team is currently administering a survey to gauge understanding and solicit feedback about the upcoming change to reusable gowns, said Marvel. The team selected the ED and intensive care units (ICUs) for implementation of the pilot program because these areas traditionally have the highest isolation gown usage rates within the hospital. The survey will capture and address any concerns staff may have about reusable gowns, such as their comfort or infection prevention efficacy. Prior to the survey, some staff members expressed concern that wearing the reusable gowns would be uncomfortably warm. To address this concern, Marvel and team have organized a "roadshow" to showcase samples of eight varieties of reusable gowns for staff to try out and determine the most comfortable options.

Marvel remarked on the importance of demonstrating benefits from a pilot before scaling implementation; therefore, the SHC will implement the reusable isolation gown pilot program in the ED and ICU before attempting an institution-level change. As issues or concerns arise during the pilot, the ED Green Team will continue to respond by investigating and problem solving, thereby establishing a strong foundation for the reusable gown program. He stated his optimism that the pilot will reflect cost savings, staff acceptance, and environmental benefits that constitute a compelling case for expanded rollout throughout the hospital, particularly given Stanford University's commitment to sustainability.

PANEL DISCUSSION

Enhanced Circularity of HCTs for PPE

Wright asked about approaches to enhancing the sustainability and circularity of production processes for both disposable and reusable HCTs. Gajanan Bhat, professor at the University of Georgia, is currently involved in research to create the next generation of PPE via melt-blowing technology. He explained that some disposable medical gowns are largely composed of polypropylene, a plastic made from fossil fuels. Disposable PPE entails a linear supply chain that involves depleting natural resources and generating waste that will not degrade for hundreds, if not thousands, of years. He added that the challenges posed by the linear supply chain for plastics extend beyond PPE to packaging and other non-health-related products. In contrast to linear supply chains, cradle-to-cradle supply chains are truly circular, turning used products back into raw materials that can be used in manufacturing. During the past 20–30 years, scientists have developed an alternative polymer, polylactic acid (PLA), that offers opportunities for sustainability innovations. Made from cornstarch, PLA is essentially plant-based. NatureWorks and other

biopolymer companies are exploring additional renewable sources, such as sugarcane, for PLA production. Bhat explained that PLA features properties comparable to synthetic polymers such as polypropylene and could potentially be used to make both reusable and disposable PPE. He noted that although manufacturers claim that PLA is biodegradable, its breakdown requires industrial composting conditions.

Bhat highlighted polyhydroxyalkanoate (PHA) as another polymer produced from vegetable oil, which is a renewable source. Manufacturers are using waste cooking oil from restaurants and mixing it with oil waste to produce PHA, a fully biodegradable polymer (Ruiz et al., 2019). Currently, PHA cannot be converted into fibers, but researchers are working to develop this capability. Furthermore, the National Institute of Standards and Technology is funding a research initiative involving several universities and industries striving to create truly biodegradable PPE from PLA, PHA, or PLA-PHA blends (Hanacek et al., 2024). After use, such products would break down into simple molecules or become raw material, Bhat explained. He is involved in research that has led to the development of N95 filtering facepiece respirators made from PLA with 99 percent filtration efficiency, the successful production of PLA spunbond polyester, and the production of singlemode-multimode-singlemode structures within PLA melt-blown fabric.

Bhat emphasized that further LCA and techno-economic analysis are needed on these innovations. Reducing the cost of biodegradable materials for PPE is of primary concern for implementation, but this will require increased investment, production capacity, and demand. Reducing cost and demonstrating the performance of polymers made from renewable sources would drive demand. He remarked that some sectors and certain applications will continue to rely on disposable PPE, but the innovation of sustainable, disposable PPE with a circular, cradle-to-cradle life cycle could meet these PPE needs while decreasing environmental effects. Overcash commented that full-scale manufacturing plants are currently operating in the United States and abroad that process PET from waste plastics by depolymerizing it, eliminating color and other components, and reforming it into PET pellets that can be used in manufacturing. The technology to similarly recycle polypropylene is in place, but it is currently processed at smaller volumes than PET. The life-cycle benefit of reusable PPE increases when products are made from materials within a circular supply chain, he added. Although circularity entails additional energy expended to recycle materials, it reduces waste.

Wright asked about findings from LCAs—particularly on cradle-to-cradle systems—concerning reusable versus disposable HCTs. Overcash replied that studies have examined the environmental implications of manufacturing disposable PPE from hydrocarbons sourced from in-

ground resources and compared these with reusable PPE on a 1000- or 10,000-use basis, finding that processing reusable PPE consumes fewer resources than producing a disposable product. He noted that these analyses consider the heavier weight of reusable HCTs.

Shelley Petrovskis, director of Marketing and Regulatory Affairs at Lac-Mac Limited, described circularity as a method that can contribute to achieving the goal of sustainability. When defined as a practice focused simultaneously on reducing materials used and prolonging the length of time a product's value remains intact, the term "circularity" applies to reusable medical gowns currently on the market. The ability to downgrade reusable gowns for alternative use once they reach end-of-life for surgical applications further extends the length of time they offer value. Melissa Dawson, associate professor at the Rochester Institute of Technology, highlighted an opportunity to shift the paradigm from considering reusable gowns as waste once they complete use life to designing gowns for eventual reclaiming and recycling. Rather than expecting reusable gowns to ultimately reach the landfill or be incinerated, they could be manufactured from reusable materials in a system designed for circularity, she remarked.

Overcash commented that he is aware of two suppliers for hospital systems that ship gowns that have completed use life to countries lacking PPE. Shawn Gibbs, dean of the School of Public Health at Texas A&M University, noted that reusable gowns are sometimes retired before they complete use life due to aesthetic factors such as color fading or the hospital logo having worn off; such gowns would be particularly appropriate for donation. Wright added that colorfastness and other aesthetic aspects sometimes involve additional chemicals in HCT manufacturing that may be of concern to HCWs. Donation could provide a mechanism for extending the length of time a product offers value without additional chemicals.

Environmental Benefits Associated with Reducing Transportation and Medical Waste

Emphasizing that reusable products constitute 80–90 percent of total HCTs in Canada and some other countries, Wright asked about the potential environmental effects of adopting reusable PPE at similar rates in the United States. She added that other countries may not accept discarded textiles from the United States in the future. Overcash remarked that when reusable gowns eliminate the purchase of disposable gowns, it yields a direct reduction of nonrenewable resource use and landfill waste. However, methods for increasing demand for reusable gowns are unclear, he said. Bhat remarked that LCAs on disposable gowns indicate the effects of packaging and transporting goods on greenhouse gas emis-

sions. He noted that the environmental footprint of both reusable and disposable PPE can be reduced through more localized manufacturing that decreases shipping distances. Overcash has calculated the effects of transporting PPE on the environment, finding that effects are less substantial than might be expected due to the lightweight nature of gowns. He clarified that reusable gowns weigh more than disposable ones, but the environmental effects of transporting reusable gowns remain relatively small compared to those generated by manufacturing processes. Petrovskis commented that U.S. purchases from one of the several manufacturers of reusable PPE based in North America eliminates the need for overseas shipping. Overcash replied that his calculations only included manufacturers based in Asia; he has not compared the environmental effects of transporting PPE from Asia with those of transporting PPE from North America.

Gibbs, a certified industrial hygienist who specializes in the disruption of high-consequence infectious diseases, highlighted a difference between transporting Category A waste—that is, material reasonably expected to contain a pathogen capable of causing permanent disability or death—and regulated medical waste. Transporting Category A waste is substantially more expensive than transporting regulated medical waste, requires far more packaging, and can involve political issues necessitating transportation routes circumventing entire states. Gibbs described how transporting a bin of disposable PPE can entail an additional 60–70 pounds of packaging material and increased mileage. Therefore, PPE that is safely decontaminated, repurposed, and reused drastically reduces end-of-life cost and environmental effects. Wright commented that as much as 70 percent of regulated medical waste in hospitals is generated by incorrect triaging of items that are not actually regulated medical waste (Duong, 2023). Thus, this additional waste unduly burdens the economic and environmental costs of transporting regulated medical waste. Overcash added that public health research has resulted in decreasing the PPE recommended for seeing patients with methicillin-resistant *Staphylococcus aureus* (MRSA) and vancomycin-resistant *Staphylococcus aureus*; this demonstrates that safely reducing PPE recommendations via deeper scientific understanding of risk would benefit the environment.

Environmental Regulations Regarding HCTs

Wright asked about regulations already in place that address the environmental impacts of HCTs and about regulations needed to adequately address these impacts. Regulations stipulate that laundries must treat wastewater—or transport it to a facility that treats it—to attain a certain level of purity before discharge, said Overcash. These regulations are

included in permit regulations established by the state in which the water will be discharged. A standard is also in place requiring laundry facilities to thermally oxidize gas emissions. Bhat remarked that European regulations on pollutants and waste are generally more restrictive than U.S. regulations. Noting that the size of U.S. land contributes to a lack of urgency in placing limits on waste, Bhat emphasized the need to invest in expediting research and development to decrease waste. Wright stated that the U.S. health care sector's carbon emissions and waste have received relatively little scrutiny, despite hospitals frequently being among the largest producers of waste in their communities. Although regulations are adequate for addressing the safety and quality of HCTs and PPE, regulations may be inadequate for associated effects on the environment, she remarked.

Petrovskis noted that the Canadian Environmental Protection Act establishes guidelines regarding air and water pollutants that apply to Canadian PPE manufacturers and are similar to those in the United States.[1] She added that Lac-Mac Limited's efforts to increase energy efficiency in PPE manufacturing include green energy sources and the use of LED lighting, which has reduced their electricity consumption for lighting by 70 percent. Overcash emphasized that many of the emissions associated with reusable and disposable gowns are generated in countries outside of North America that manufacture and export the raw materials or the finished products to the United States. In response to a question about measures to prevent unregulated contaminants from the laundry process—such as plastic microfibers from synthetic fabrics—from entering water treatment systems, Bhat replied that this is an ongoing issue that companies are working in earnest to address.

Drivers of Reusable PPE Adoption

Replying to a question about the factors that underlie the higher adoption rate of reusable HCTs in Canada versus the United States, Petrovskis noted that Canadian commercial laundry facilities successfully highlighted the merits of reusable HCT programs to customers. Market forces in favor of disposable PPE are at play, yet commercial laundries retain customers by consistently providing a safe, reliable product that meets performance expectations. She remarked that during the COVID-19 pandemic, when PPE supply shortages drove U.S. health care facilities to source products outside of the United States, she was struck by their lack of understanding about how reusable PPE programs operate. For example, many health care facilities did not understand the importance of partnering with a laundry facility for safe reprocessing.

[1] Canadian Environmental Protection Act, 1999 (S.C. 1999, c. 33).

Gibbs commented on the initial investment involved in establishing a reusable respirator program. Given a healthy supply chain, hospitals can purchase disposable filtering facepiece respirators for just a few dollars apiece, depending on purchasing power. A reusable elastomeric respirator costs up to a few hundred dollars plus additional costs for the associated replaceable cartridges. However, when the supply chain for disposable respirators is strained—as was the case during the COVID-19 pandemic—reusable respirators carry added benefit, particularly given that an elastomeric respirator cartridge lasts weeks to months.

Advocacy for Sustainable PPE

Wright asked about advocacy approaches to increase adoption of sustainable, environmentally friendly PPE. Marvel remarked that effective advocacy largely hinges on understanding staff concerns and using—or creating—relevant data to support efforts to implement reusable PPE. The SHC ED Green Team seeks to be inclusive by encouraging and responding to input from a range of perspectives, including nurses, technicians, residents, physicians, and pharmacists. This can highlight ongoing issues (e.g., the discarding of pulse oximeters) and gauge willingness to adopt reusable PPE. For instance, the reusable gown roadshow that Marvel's team developed is designed to simultaneously gather input and provide education about the efficacy of reusable HCTs in infection prevention. They will conduct a survey along with the roadshow to gauge staff members' concerns and willingness to adopt reusable gowns; this feedback will inform educational campaigns to address major concerns. Additionally, recommendations about product selection will be based on the favored reusable gown tested during the roadshow. He noted that institutional support is already in place and that the reusable gown initiative could potentially roll out in the ED within the next 2–3 months. After implementation, the ED Green Team will collect data on gown usage patterns, attrition rates, and other information needed to facilitate institution-wide implementation. Infrastructure needs associated with scaling the pilot—such as space considerations and laundering facility contracts—will also be identified and addressed before implementation expands.

Overcash commented on the common concern that reusable gowns would be uncomfortable to wear. He has only located one study on the comfort of reusable gowns, which involved surgeons at Walter Reed National Military Medical Center receiving randomized gowns before surgeries without knowing beforehand whether the gowns would be disposable or reusable (Conrardy et al., 2010). Upon completing the surgery, participants rated the comfort of the gown, with reusable gowns overwhelmingly reported to be more comfortable than disposable ones.

Bhat raised a concern that potential resistance from the disposable PPE industry could postpone enactment of regulations regarding end-of-life PPE disposal. He argued that technology is currently in place that would enable industry to meet more restrictive environmental regulations. Advocates should share data to educate representatives at all levels of industry and government about the current capacity to increase sustainability in PPE, said Bhat.

In response to a participant's question about how incentives could be used to increase adoption of reusable PPE among HCWs, Wright remarked that HCWs typically do not have a choice between reusable or disposable products. Efforts to educate HCWs about reusable PPE, especially opportunities to try on products, could generate interest and buy-in during implementation of reusable PPE programs. Overcash mentioned instances of hospital physicians collectively and successfully lobbying for a transition to reusable PPE in the facility. He remarked that physicians are highly valuable to hospitals and can leverage this influence with hospital leadership, who have a vested interest in simultaneously achieving cost and environmental savings.

5

Economic Impact

The fourth session of the workshop examined the economic impacts of increasing the use of reusable versus disposable health care textiles (HCTs) with a focus on both short- and long-term infrastructure investments for health care facilities and value holders. A panel discussion featured perspectives from personal protective equipment (PPE) manufacturing, U.S. trade policy, and the health care system. Barbara Strain, principal at Barbara Strain Consulting, LLC, moderated the session and presented an overview of the value analysis process within health care settings.

VALUE ANALYSIS 101: ATTAINING OVERALL VALUE USING VALUE ANALYSIS PROCESSES

Strain described how value analysis has evolved from its origin in the 1940s as "value engineering." A variety of industries have used value analysis to express outcomes in relation to the costs to achieve outcomes, but the concept did not become prevalent in health care until the 1980s or 1990s. Value is described as equal to quality—referring to outcomes, safety, services, or other measurable components—divided by the cost of providing that level of quality. Value analysis compares the difference between the cost to obtain current outcomes and the projected cost to obtain better outcomes. Conducting a value analysis involves a series of evidence-based decision-making processes. With the facilitation of trained value analysis professionals, a multidisciplinary group of subject-matter experts proceeds through this series of processes. The first process involves determining and validating the need, identifying gaps in the

current state, and envisioning the future state. Next, the data collection process gathers information from a variety of sources, such as clinical-based evidence, financial evidence, and stakeholder identification. Data analysis is then conducted and contracts, project evaluations, or any other data needed to create a value statement are assembled in a report or executive summary. The next process, reaching a consensus decision, involves a multidisciplinary group of subject-matter experts to review the findings and arrive at a decision. Once a decision is reached, implementation logistics, education needs, and changes in practice, policies, and/or procedures are carried out. After implementation, the final process in value analysis is results monitoring, which enables assessment of whether original goals and needs have been met, Strain noted.

Using Value Analysis to Guide PPE Decisions in Health Care Settings

Value analysis related to both reusable and disposable PPE products considers upstream and downstream factors and all major operations, including those outside of health care, said Strain. She outlined factors pertaining to the five process steps of a value analysis for the implementation of reusable HCTs. Determining the need for reusable PPE involves reviewing sustainability goals and considering a range of personal and logistical factors. For instance, the sizing and fit of PPE, any issues related to donning and doffing, and any skin reactions reported by staff and visitors should be considered. Strain emphasized that PPE is not only used to protect staff and patients, but also visitors who are asked to wear isolation gowns and other HCTs when visiting patients with certain conditions. Thus, visitors constitute a portion of the PPE customer perspective. This process also considers waste disposal concerns related to costs, volumes, and environmental effects. Safety factors, such as reported fluid breakthroughs or exposures within the health care setting, could contribute to determination of need. Numerous logistical concerns—such as contracts with PPE providers, storage capacity for both clean and soiled reusable HCTs, supply chain disruptions, and any legal matters—should also be considered.

Strain explained that the determined need should drive action, with the data collection process linking back to that need. Data sources for the data collection process include (1) internal safety, quality, and employee health reports; (2) a list of all medical gowns purchased that includes manufacturer(s) and cost; and (3) annual quantities purchased and the associated cost. A list of manufacturers selling products that meet the criteria set by the multidisciplinary group should be obtained in addition to contract availability for gowns and laundering services. A comparison of the various costs and waste associated with disposable and reusable

PPE should be conducted. Product evaluations and feedback should be collected from staff that reflect the diversity of the people using PPE, such as nurses, physicians, aides, and staff from the emergency department (ED), operating room, and outpatient settings. Data collection via time studies, use of methodologies that increase value by reducing waste and eliminating components that do not contribute toward better outcomes, and review of clinical-based evidence enables fact-based decision making. Data collection should also include regulatory reviews, recalls, supply issue reports, and reports made to the U.S. Food and Drug Administration Manufacturing and User Facility Device Experience database. Professional organizations can also serve as data sources. This process should consider information related to supply chain resiliency and to the sustainability of both internal and external processes and their associated costs. Strain noted that this list of PPE value analysis data considerations is not exhaustive and additional data sources may be relevant.

The next process is analyzing data across the value chain. Strain clarified that the supply chain, value chain, and sustainability chain are separate frameworks that merge at various points. The data analysis calculates and compares current cost and outcomes with the projected cost for potential new outcomes. This involves clinical, safety, risk, and quality comparisons to mitigate any risks and ensure the safety of staff, patients, and visitors. Input collected from customers, from evaluation results, and via networking is then assembled and analyzed. The fully loaded cost—that is, a calculation of all the direct and indirect costs—is determined by including the costs of manufacturing, transportation, distribution, storage, use, internal and external disposal and/or laundering, and sustainability, said Strain.

The process of reaching a consensus decision should be rooted in support from executive leadership obtained at the outset of the change effort, Strain stated. The effort of convening a group and working through the prior processes could be wasted if chief executives are against the initiative. A fully formed value analysis process features an executive steering committee that delivers messaging throughout the organization. In reaching consensus, all group members voice their perspectives. Additional data may be required to address identified gaps. A value statement is prepared that includes a full explanation of the execution of the analysis. Discussion is followed by a vote, and if the consensus is to move the change effort forward, the implementation plan is initiated. The final process of the value analysis is monitoring results. This process involves determining key metrics for monitoring the outcomes of the initiative and an appropriate timeline of milestones. In cases where one or more metrics exceed parameters, the root cause is determined. Strain concluded that monitoring results enables assessment of whether the determined need has been met and goals have been attained.

CASE STUDY: COSTS ASSOCIATED WITH STOCKPILING OF RESPIRATORY PROTECTIVE DEVICES

Gio Baracco, professor at the University of Miami, described a comparative cost analysis on stockpiling respiratory protective devices (RPDs) during an influenza pandemic. A literature review of cost evaluations of PPE revealed that cost analyses are conducted with different cost bases, such as: the cost of protecting one health care worker (HCW) against a specific hazard, the cost of using a specific type of PPE in a certain scenario (i.e., usual clinical practice during a pandemic), or the cost of stockpiling a certain type or combination of types of PPE. Baracco and colleagues (2015) analyzed the cost of stockpiling various types of RPDs during an influenza pandemic, using the cost of stockpiling as the basis. The resulting comparative cost analysis examined five RPD use strategies[1]:

1. Disposable N95® respirators only;[2]
2. Reusable elastomeric respirators only;
3. Powered air-purifying respirators (PAPR) only;
4. Reusable elastomeric respirators for medical and nursing personnel and disposable respirators for other HCWs; and
5. Extended use or reuse of disposable N95 respirators.

The approach used to estimate the cost of stockpiling RPDs involved an existing model that calculates how a pandemic might affect community health care use and the staffing needs for a defined population, said Baracco. The population is defined in relation to the health care entity. For a health care system, the defined population could be the hospital's market share within a community; for a county public health department, the population could be the entire community; for agencies such as the Centers for Disease Control and Prevention, the population could be the entire United States. The model's estimates were applied to each usage strategy to determine the size and composition of the corresponding stockpile. Next, they identified the warehouse space and inventory management needs for each RPD stockpile, and then calculated the purchasing and storage costs. In determining the number of devices to stockpile, the metrics used in estimating need varied between strategies. Whereas the metric for disposable, single-contact devices is the number of contacts between an HCW and a patient, the metric for using a disposable item for multiple contacts is the

[1] Baracco explained that PAPRs are battery-powered respirators that have a pump, hose, and fluid; he also clarified that extended use or reuse of disposable N95 respirators entails use of the same respirator for a specified number of hours rather than for a single encounter.

[2] N95 is a certification mark of the U.S. Department of Health and Human Services (HHS) registered in the United States and several international jurisdictions.

estimated number of patient contacts within a specified number of hours. The metric for reusable respirators assigned to individuals is the estimated number of HCWs to whom the PPE is assigned, Baracco explained. Calculations for reusable RPDs may include accessories that will need to be replaced, such as filters, batteries, tubing, hoods, or straps. In such cases, the use patterns of the reusable RPD and each accessory must be considered in estimating needed quantities.

Baracco and colleagues created a simple model within a spreadsheet that contained outbreak characteristics being estimated, inputs for the PPE being evaluated, outputs such as cost and space, and, ultimately, the total annual cost prorated to the PPE's shelf life. He underscored that this cost analysis was conducted several years before the COVID-19 pandemic, when actual pandemic PPE usage rates were unavailable. Estimates were based on prior pandemics in terms of infection rate, numbers of patients that would seek care, hospitalization rates, intensive care unit (ICU) use, mechanical ventilation needs, mortality rates, length of hospital stay, and other metrics. From these numbers, they estimated how many patient contacts various health care scenarios would necessitate. These scenarios included a patient who presented at the ED but was ambulatory, an ED patient who required hospital admission, a patient staying in a hospital ward, a patient admitted to the ICU without mechanical ventilation, and an ICU patient on mechanical ventilation. After establishing patient contact estimates, they ascertained the unit cost for each RPD and accessory. Given that stockpiling involves storing supplies, they also collected data on the number of units packaged per box, the box dimensions, and how many pallets could be stacked. The shelf life of products was used to prorate the cost of acquisition. Estimates of warehouse leasing, utilities, and personnel costs to manage inventory were also considered.

Baracco and colleagues calculated estimates of the annual cost to stockpile RPDs for a population of 1 million people for each of the five RPD use strategies. Reusable elastomeric respirators were the least expensive RPD strategy, with an estimated annual stockpiling cost of $75,000–$125,000. The estimated annual stockpiling cost for single-use disposable N95 respirators was approximately eightfold that of reusable elastomeric respirators, at $500,000–$1 million annually. He noted that PAPRs were prohibitively expensive to acquire and stockpile, costing over $18 million per year. The strategy of providing reusable elastomeric respirators for medical and nursing personnel and disposable respirators for other HCWs was estimated to cost $274,000–$526,000 yearly. The cost of reusing disposable N95 respirators for 2.5 hours—rather than disposing of them after each patient encounter—was $87,000–$160,000 per year; extending use to 4 hours brought the cost down to that of reusable elastomeric respirators.

Baracco summarized limitations of the comparative cost analysis. In modeling a pandemic, the study estimated costs for an unpredictable event and was not based on actual RPD usage rates. Furthermore, the use of RPDs outside clinical care of infected patients was not considered. As the study was limited to health care settings, it does not account for the mask recommendations and policies issued for the general public during the COVID-19 pandemic. Costs incurred by disinfecting PPE, fit testing, training staff, distribution, waste management, and other activities were not included in cost estimates. Baracco noted that the study also did not account for factors important for product selection, such as the degree of protection offered, tolerability, user preference, and ease of storage.

PANEL DISCUSSION

Economic Considerations Related to PPE Supply Chains and Trade Policies

Strain asked about key economic challenges affecting the balance of reusable and disposable PPE production and adoption. Laura Thurston, director of laundry services at Intermountain Health, described difficulty in predicting and adjusting to customers switching from one type of PPE to the other. She noted that during the COVID-19 pandemic, vendors allocated PPE to health care systems based on past purchase history. Therefore, Intermountain Health was unable to obtain items that they had not previously used. This scenario is relevant to stockpiling and surge planning efforts. Merrow highlighted the economic effects of manufacturing programs in local communities. When PPE is made in the United States from domestically produced fabric, the number of people who benefit from the products extends beyond those who wear them. He remarked that the number of U.S. jobs affected by fluctuations in the production of medical devices, particularly PPE, is poorly understood. During the COVID-19 pandemic, Merrow Manufacturing scaled production to address PPE supply shortages, and in so doing created an estimated 750 jobs directly related to production. He commented that four times as many jobs were likely created throughout the PPE supply chain. Dollars spent on regionally produced goods carry economic impact for U.S. communities. Merrow added that substantial, consistent demand brings down product cost; thus fluctuation in the U.S. demand for PPE is a primary consideration in the economics and viability of manufacturing PPE.

Laurie-Ann Agama, acting assistant trade representative for textiles at the Office of the United States Trade Representative (USTR), explained that USTR is responsible for developing and coordinating U.S. international trade commodity and direct investment policy as well as oversee-

ing negotiations with other countries. As acting assistant trade representative for textiles, Agama advises Ambassador Katherine Tai, the U.S. Trade Representative, on textile and apparel trade policy matters. She also closely collaborates with the U.S. Department of Commerce and U.S. Customs and Border Protection on (1) textile trade policy development; (2) the implementation, monitoring, and negotiation of trade agreements; and (3) the enforcement of textiles provisions in existing U.S. trade agreements. In the wake of the COVID-19 pandemic disruptions to global supply chains, including textiles and other vital supplies for PPE production, the Biden administration is working to proactively strengthen supply chain resilience to mitigate the effects of future disruptions, said Agama. As part of this effort, USTR is crafting a new approach to trade and investment policy that is supported by innovative tools and strategies. Closely integrated and coordinated with domestic economic policy and support for U.S. manufacturing, this approach addresses supply chain risks posed by unfair trade practices. Furthermore, this approach creates opportunities for businesses to increase sourcing options, including domestic sources, and facilitate the movement of supply chains to trusted partners. She described that this practice, called "friendshoring" or "nearshoring," strengthens the labor standards and environmental protections governing global supply chains.

Agama highlighted the tariffs levied against China under Section 301 of the Trade Act of 1974, which are currently undergoing a statutory 4-year review.[3] This review was initiated to examine matters including the effectiveness of the tariffs toward the elimination of China's acts, policies, and practices involving the unfair and harmful acquisition of U.S. technology. These tariffs have had measurable and substantial effects on supply chains and, as part of the review, USTR is currently considering the overall structure of the tariffs, including which products should be subject to additional duties. In December 2023, USTR extended all Section 301 exclusions—including 352 reinstated exclusions and 77 exclusions related to the COVID-19 pandemic—through May 31, 2024, and these reinstated and COVID-19–related exclusions cover PPE products. Additionally, USTR opened the docket for public comments on the possible extension of specific exclusions. The docket closed on February 21, 2024, after receiving 866 comments. In considering whether to extend exclusions, the office is currently reviewing these comments. The focus of the evaluation will be on the availability of products covered by the exclusion from sources outside of China and on efforts to source products domestically and from third countries, Agama noted.

[3] Trade Act of 1974, Public Law 93-618, 93rd Cong., 2d sess. (January 2, 1975), 19 U.S.C. §§ 2411–2420.

Economic Assessment Related to Increased Adoption of Reusable PPE

Strain asked how to monitor the success of PPE sustainability programs. Merrow replied that he monitors demand to determine whether Merrow Manufacturing is influencing customers to continually—or increasingly— choose the domestic PPE supply chain. Noting that product innovation can drive demand, he highlighted the opportunity for innovation within the domestic supply chain through an iterative approach involving collaboration with health care systems. Thurston commented that Intermountain Health measures cost per use and calculates a cost comparison between reusable and disposable PPE. The cost of reusable PPE includes numerous factors throughout the supply chain—such as distribution, labor, storage, laundering, and collection of soiled items—in addition to the acquisition cost. These costs are then divided by the number of uses recommended by the manufacturer. The cost of disposable PPE includes expenses for collecting and transporting waste. She commented on costs of chemical discharge into wastewater through local sewer systems from laundry operations processing reusable PPE and HCT products. Thurston remarked that after the disposable PPE supply shortages during the COVID-19 pandemic, consideration is also given to maintaining a balance of products. Given the numerous metrics at play, organizations must prioritize factors in selecting PPE, she added.

In addition to environmental savings, reusable gowns carry cost savings for hospitals, Overcash highlighted. He collected 2021 data from six laundry facilities on the processing services provided to 179 hospitals and associated incurred charges. He calculated the cost of purchasing new disposable gowns equivalent to the number of isolation gown processing cycles conducted by the laundry facilities. Comparing the cost of purchasing disposable gowns with the cost of purchasing and laundering reusable isolation gowns, he identified a 52 percent cost savings by opting for reusable gowns. This signifies that hospitals using disposable isolation gowns pay 200 percent of the cost of using reusable gowns. Overcash and his colleagues also conducted this cost analysis for surgical gowns and incontinence pads as well as environmental cleaning devices, flat mops, and wipers. The cost savings were similar or greater than the isolation gowns savings, with reusable products delivering up to 90 percent cost improvement. He emphasized that these savings are based on actual cost analysis and are not hypothetical. Furthermore, in consulting with HCT laundry facilities in Europe, where reusable products constitute an estimated 70–80 percent of PPE used in health care organizations, Overcash learned that cost savings would scale in the United States with increased use of reusable PPE.

PPE Sustainability Metrics and Barriers

In response to a question about methods of measuring sustainability in the PPE industry, Agama replied that the COVID-19 pandemic and resulting PPE supply shortage crisis revealed the medical community's reliance on disposable PPE and the need for alternatives. USTR data indicate that approximately 44 million nonwoven PPE items are used by frontline HCWs each day, generating 15,000 tons of waste destined for landfills or incineration. She remarked that the upfront purchase cost of reusable PPE is a key concern for health care facilities. Although demand can drive decreases in cost, increasing the production of reusable HCTs to lower the cost could foster demand, thereby increasing HCW access and use of reusable products. A relative decline in purchases of disposable PPE could benefit the environment and natural resources. Agama commented that more research is needed to inform policy decisions that enable better outcomes.

Merrow stated that although reusable PPE manufacturers are working to increase sustainability related to PPE, limited interaction between health care systems and manufacturers poses a challenge to achieving sustainability goals. Merrow Manufacturing has created a medical gown that can maintain protective properties through 200 industrial laundry wash cycles, enabling each gown to remain in service for a lengthy period. Furthermore, the gown is made from recycled products. Technology is in place to build Level 1, 2, 3, and 4 medical gowns from 100 percent recycled material. Moreover, Merrow Manufacturing can craft bespoke products designed for individual health care systems and providers via a circular supply chain. Gowns in a circular supply chain are manufactured, shipped to health care facilities, used for months while being laundered at facilities increasingly adopting sustainable practices, shipped back to Merrow Manufacturing at use life completion, and in turn shipped to the material manufacturer to recycle anew into raw material. This capability is in place; however, while many health care systems have established environmental, social, and governance programs, their stated goals are not aligned with uptake of innovative, sustainable products, said Merrow. The peak of the COVID-19 pandemic demonstrated the capacity to manufacture a million reusable gowns per week, yet current demand is one-tenth of that capacity.

Noting that cost parity between reusable and disposable gowns was achieved during the supply disruptions of the COVID-19 pandemic, a workshop participant asked why health systems abandoned reusable PPE programs once availability of disposable PPE was restored. Merrow remarked that current hospital system cash management does not support reusable PPE programs. In the mid-1990s, reusable medical gowns were predominant and hospital systems had laundering and manage-

ment operations in place. However, hospitals moved toward disposable products in the 2000s; Merrow pointed to cash flow patterns as a driver of this trend. Although amortized costs of reusable PPE generate savings in comparison with disposable counterparts, the upfront costs are higher for reusable products.

Thurston commented that the cost of reusable gowns shows some variance in response to prices for cotton and other raw materials. She remarked that stagnation in health care adoption of reusable PPE can be driven by contracts with vendors. When a health care system has a contract in place with a specific vendor, they are likely unaware of innovative products available from competitors. Thurston noted that national organizations could play a role in raising awareness of innovation in PPE. During the COVID-19 PPE supply shortage, Intermountain Health was processing 1,500 reusable gowns per day for a single hospital. However, as soon as disposable gowns became available, this figure dropped to 100 reusable gowns per day. She remarked that health systems often do not consider cost and sustainability in these decisions; rather, they default to disposable products because they are familiar and convenient. Nonetheless, hospitals are once again exploring reusable PPE as they investigate methods of reducing costs and waste in the supply chain.

Mechanisms to Increase the Adoption of Reusable PPE

Given the limited usage of reusable PPE, Strain asked about processes, regulations, or other efforts that could increase adoption rates. Agama replied that USTR is aware of the reusable PPE manufacturing capacity highlighted by Merrow and how the textile industry pivoted during the COVID-19 pandemic to produce PPE. She said USTR is focused on this issue and actively monitoring it. To foster supply chain resilience and create more opportunities for manufacturers, USTR is working on wide-ranging engagement efforts to better understand the perspectives of stakeholders—including the textile, apparel, and health care industries—on how to support the manufacturing base. Agama referenced USTR announcements expected in coming weeks about these issues.

Merrow expressed optimism about reusable PPE adoption related to three current dynamics. In the past 3 years, advancements in sustainable materials have enabled production of high-quality medical products fundamentally different from the previous generation. He remarked that the availability of these sustainable health care products is reaching critical mass and offers an opportunity for increased sustainability in the U.S. health care system. Additionally, the COVID-19 pandemic spotlighted how U.S. manufacturing capacity limits affect the supply chain. Merrow commented on an acute awareness in the U.S. government that current

manufacturing capacity is not improving and requires attention. Also, in anticipation of another global crisis, manufacturers and health care systems are working to increase supply chain resilience while decreasing risk. These events provide an opportunity to create substantive change in the supply chain, said Merrow.

Thurston noted that radio-frequency identification (RFID) and other tracking innovations have minimized the labor involved in monitoring each reusable PPE item's use life, ensuring that PPE retains its protective barrier properties. Intermountain Health is exploring ways to facilitate the use of reusable HCTs, such as designing products that are easy to don and doff and that can be folded into less bulky configurations that lie flat, making them easier to store and to quickly grab when needed. Such features improve ease of use and decrease resistance to reusable HCT adoption, she maintained.

In response to a question about the role of incentives in increasing reusable PPE adoption, Merrow remarked that incentives for health care systems to choose reusable products should be put into place because reusable products are sustainable and provide value within a sustainable supply chain. Additionally, incentives for U.S. health care systems to purchase PPE regionally should be established, he said. Merrow also called for federal and state organizations to lead by example in purchasing products that are better for the environment and better for U.S. communities. Thurston commented that the development of best-practice standards issued by the federal government could increase acceptance and adoption of reusable PPE. Monetary incentives can be helpful, but prices will inevitably increase with time. An established best practice, universally accepted in the medical and manufacturing industries, would help foster understanding that reusable PPE is effective and efficient, she maintained.

Agama spoke of the need for consumer education to drive demand for reusable PPE within health care settings. Overcash emphasized the influence that surgeons could have by collectively asking hospital leadership to convert to reusable PPE for the environmental and cost benefits it offers and to request that the GPO locate laundry facilities that meet CDC guidelines. He remarked that PPE is one of the highest operating costs within a hospital, and GPOs have an opportunity to respond to health care systems and lower costs. Strain commented that in the institutions where she has worked, surgeons prefer reusable gowns due to patient-safety factors, such as reduced lint.

PPE Workforce Challenges

Noting nationwide workforce challenges, Strain asked about current workforce demand within U.S. PPE manufacturing. Merrow replied that

a misconception persists that the U.S. manufacturing workforce is insufficient to meet need. He contended that the issue is not worker shortage, but rather an inconsistent demand for work. Frequently, PPE manufacturing jobs increase and decrease in response to product demand, resulting in unpredictable work availability for employees. It is possible to scale PPE manufacturing, if scaling entails steady jobs and that investment is made in automation. Merrow remarked that technology for automated material handling, which is incorporated into all soft goods manufacturing, is particularly needed in health care manufacturing due to quality standards. He posited that automated material handling and quality assurance programs, combined with consistent demand, would enable tremendous scaling within the industry. Investment in automation and in strengthening long-term demand signals to manufacturers that implementing long-term workforce training programs would generate growth, said Merrow. Agama added that U.S. trade policy is focused on supporting domestic economic policy in U.S. manufacturing, including textiles, and prioritizes job creation in the United States. USTR is currently working to support U.S. workers and ensure that greater numbers of products are made in the United States. Feedback from U.S. textile industry stakeholders indicates that there is capacity for sustainability, supply chain resiliency, and scaling capability, she noted.

Thurston commented that shortages in the entry-level workforce have led Intermountain Health to explore investments in automation. In addition to technology that reduces labor needs, such as RFID tracking, automation helps maintain the hygienic properties of PPE by efficiently moving laundered products from the washer to the dryer and into packages without manual contact. Although commercial laundries continue to rely on human labor, opportunities for automation offer numerous benefits.

Reusable PPE Data Gaps

To a question about research needed to demonstrate the benefits of reusable PPE, Merrow commented on the need to analyze supply chain resiliency of reusable PPE versus disposable products. Although a health care system that has adopted reusable PPE should face fewer PPE supply shortages during a health care crisis than systems that rely on disposable PPE, he was unaware of an analysis that has achieved consensus on this matter. Studies have demonstrated that cost parity between reusable and disposable PPE is possible, even when accounting for laundering and management costs. However, generating more robust data in this area could further highlight the advantages of reusable PPE, particularly given the sustainability benefits it offers. Research is also

needed on the environmental benefits of a regional supply chain that calculates the carbon footprint of regionally produced reusable PPE versus imported products, added Merrow. Agama remarked on the usefulness of case studies that communicate the complexities of the supply chain and value analysis in an easily understandable format. Given that available literature indicates that both the cost and environmental effects of reusable PPE are better than disposable counterparts, Overcash emphasized the need for economists to identify the barriers to adoption that prevent health systems from taking advantage of those financial and environmental benefits.

6

Safety and Quality Considerations

The fifth session of the workshop aimed to characterize the safety and quality considerations associated with increasing the adoption of reusable versus disposable health care textiles (HCTs) within health care settings. A panel explored the impact of reusable HCTs use on patient and health care worker (HCW) safety using a risk-based assessment framework. Nicole McCullough, vice president of application engineering and regulatory affairs in the Personal Safety Division at 3M Company, introduced and moderated the session. She emphasized that product performance regulations are critical in helping to ensure that products are safe and functional for patients and end users. Guidance typically provides direction on product selection and use. Regulations for medical devices ensure that the design, manufacture, and quality systems meet U.S. Food and Drug Administration (FDA) requirements. Given that few reusable medical gowns have received FDA clearance compared with disposable gowns in the past two decades, adapting regulations and guidance to ensure applicability to reusable gowns should be explored, said McCullough. The evolution of current regulations and guidance could also enable improved adoption rates of reusable PPE while better addressing the safety, efficacy, and usability of reusable gowns. Numerous factors may affect the feasibility and acceptance of reusable HCT programs by health care institutions, such as health care education and risk categorization profiles. McCullough noted that reusable respiratory protective devices (RPDs) share some similarities with reusable HCTs, and lessons learned about use of the former may translate to the latter.

CASE STUDY: IMPLEMENTATION OF A REUSABLE ELASTOMERIC RESPIRATOR PROGRAM DURING THE COVID-19 PANDEMIC

Sara Angelilli, director of education and professional practice at Allegheny Health Network (AHN), presented a case study on the medical use of elastomeric half mask respirators (EHMRs) during the COVID-19 pandemic—with a focus on the EHMR disinfection and decontamination procedures instituted—and she highlighted current gaps in the evidence base. In 2020, at the onset of the COVID-19 pandemic, HCWs preferred disposable N95 respirators for their RPD needs. However, challenges in the supply chain disrupted availability of disposable respirators. To ensure that all HCWs had adequate access to the personal protective equipment (PPE) needed to safely care for patients, AHN explored the use of EHMRs. Traditionally, EHMRs have been used in industrial settings, and use in health care settings was very limited at the start of the pandemic. Therefore, AHN had to consider how to safely translate use to the health care setting. Angelilli outlined implementation considerations, including the responsibility of program leaders, determinants of user assignments and deployment methods, fit testing and user training, decontamination strategies, and storage strategies.

During initial implementation, a shared-user model featured a central distribution channel in which respirators moved from central supply to hospital units at the start of each nursing shift, Angelilli explained. At the beginning of a shift, the nurse would retrieve an EHMR and use it throughout the shift while implementing intermittent disinfectant protocols between uses. At the completion of each shift, the nurse would send the respirator to the central sterile processing department for the centralized decontamination process. As AHN secured more respirators, the program shifted from this shared-user model to an individual-user model. With the shift in user models, the cleaning and disinfection models also changed.[1] As is the case with all devices, AHN follows the manufacturer's instructions for use (IFU) and followed the EHMR instructions outlining specific details for cleaning and maintenance. Additionally, Angelilli noted that U.S. Environmental Protection Agency (EPA)-approved disinfection agents must be used.

[1] Angelilli defined "cleaning" as the removal of visible soil from the surface of an object using water and a detergent, and she defined "disinfection" as the elimination of all pathogenic organisms, except bacterial spores, using a liquid chemical or wet pasteurization method.

Centralized Decontamination Process

In transitioning use of EHMRs from industrial to health care settings, Angelilli emphasized that disinfection protocols were vitally important to ensuring that the respirators did not become vehicles for transmitting diseases and pathogens from one person to another. Using a centralized decontamination process, AHN's sterile processing department—staffed by employees specifically trained in cleaning, decontamination, and sterilization—decontaminated the EHMRs and ensured that IFUs were dutifully followed. The instructions for the specific EHMR used at AHN directed use of specific germicidal detergent and quaternary ammonium-based disinfectants registered with EPA and validated against SARS-CoV-2. Angelilli noted that literature often indicates that cleaning and disinfection should be performed as two separate steps, but AHN performed these processes in a single step in compliance with the IFU. The centralized decontamination process began with sterile-processing department staff donning appropriate PPE. Next, staff disassembled the respirator and cleaned and disinfected the facepiece, yoke, and head strap by soaking components in diluted decontamination detergent for 10 minutes. While those components soaked, staff disinfected the filter cartridges by wiping the casings with an EPA-approved quaternary agent or with a specific disinfectant wipe approved for use by the EHMR manufacturer. At the completion of these steps, staff rinsed the facepiece, yoke, and head strap and allowed all components to dry for 1–2 hours. Once components were dry, staff reassembled the components and checked the respirator for safety before returning it to a hospital department for use in patient care, said Angelilli.

Point-of-Use Decontamination Process

In addition to the centralized decontamination process, AHN implemented a point-of-use protocol for instances when HCWs removed their respirators and needed to decontaminate them between intermittent use. Angelilli explained that the point-of-use protocol increased respirator availability by enabling each EHMR to be used for an entire shift. The method used in centralized decontamination was not feasible on hospital floors, because they lacked the space required to correctly dilute the decontamination detergent, and floor staff were not trained in this process. Therefore, AHN contacted the manufacturer for instructions on a more convenient, point-of-use decontamination method. Through this collaboration, AHN determined that the specific disinfectant wipe approved for use by the EHMR manufacturer met the qualifications for cleaning and decontaminating respirators and would not prematurely

break down any of the components. Furthermore, the wipes are approved by EPA and are validated against SARS-CoV-2. Staff received training on the point-of-use decontamination protocol, which began by wiping down all surfaces of the respirator and casings. The IFU specified that as many wipes should be used as necessary to achieve visible wetness on the surfaces. The wipe IFU indicated a "wet contact" time that HCWs adhered to. Angelilli noted that supply shortages necessitated involvement of multiple sanitary wipe vendors and the wet contact time varied between products, ranging from 2 to 10 minutes. This variance necessitated staff training to ensure compliance with various IFU. After completion of the disinfection process, the respirators were dried thoroughly to eliminate the risk of eye irritation posed by wet disinfectant. Once the respirators were dry, staff conducted a five-point device check to ensure that (1) valves were intact, (2) the elastic head band continued to stretch and spring back to form, (3) the facepiece was free of cracks or distortions, (4) the filters were dry, and (5) the filters were securely attached to the facepiece. After completing the five-point device check, HCWs could then safely store the EHMR in a paper bag or on an identified storage hook between uses.

Respirator Decontamination Research

Angelilli emphasized the importance of protecting staff and patients from the transmission of airborne infectious particles that could potentially settle on the surface of respiratory protective equipment. At the time that AHN established these protocols, limited evidence was available on the effectiveness of RPD cleaning and decontamination protocols, with much of the available literature focusing on the influenza virus (Hines et al., 2020; Lawrence et al., 2017). As such, a need persists for research comparing the effectiveness of cleaning, decontamination, and cleaning plus decontamination. Such research would facilitate the issuance of clinical practice guidelines and evidence-based guidelines for the protection of HCWs and the promotion of safe practices. She highlighted a study on RPDs used during aerosol-generating procedures for COVID-19 patients in which no samples tested positive for COVID-19 contamination (Shah et al., 2023). Furthermore, both centralized and intermittent decontamination methods were used on the devices tested, and the authors concluded that these practices in conjunction offer additional opportunities to decrease microbial load on the surface of respirators than either method in isolation. Angelilli added that the amount of contamination found on surfaces during this time frame varied significantly, ranging from 8 to 87 percent.

PANEL DISCUSSION

Panelists representing various sectors relevant to reusable HCTs delivered introductory remarks before opening the discussion.

Health Care Worker Level

Jill Morgan, critical care nurse at Emory University Hospital, serves as a co-chair of the PPE working group for the National Emerging Special Pathogens Training and Education Center, which is funded by the Department of Health and Human Services Administration for Strategic Preparedness and Response. She recalled that when she became an emergency department and critical care nurse 24 years ago, she knew very little about PPE. She was unaware of standards and risk levels, and she did not know that selection of PPE should be based on anticipated level of risk. Rather, she wore whatever PPE products were provided in her isolation cart or supply closet. Now, drawing on decades of experience, Morgan wants to ensure that the PPE she is provided will keep her safe. She questioned whether current PPE standards are adequate, given that they are based on water repellency and that water does not necessary reflect the physical properties of blood and other body fluids. Expressing her concern about the risks of exposure to blood and other potentially infectious materials, Morgan stated that HCWs have a right to be protected from such exposures. The adoption of PPE programs should consider HCW workflow, PPE donning and doffing practices and locations, product fit and comfort, and user-friendliness with practical features such as a neck closure that can be easily untied after use, said Morgan.

Health Care System Level

Mark Shirley, director of integrated resiliency management at Sutter Health, provides employee health and safety guidance and aligns health and safety practices across the Sutter Health care network. Noting a gap in understanding of which PPE products are best for the health and safety of employees and patients, he highlighted an opportunity to improve HCW understanding of performance standards in appropriate risk-based selection of PPE. Shirley remarked on misinformed distrust of reusable HCTs, which is due in part to a brand of surgical gowns that performed poorly and allowed strikethough—an issue brought to the public's attention by media reports in 2016 (Cooper, 2016). He underscored a need for education about the safety of reusable surgical gowns.

HCT Functionality and Performance

Performance Comparison and Physiological Stress

Meredith McQuerry, associate professor and director of the ThermaNOLE Comfort Lab© at Florida State University, is a clothing comfort physiologist who studies how PPE and clothing affect human performance. Her areas of focus include design modifications to improve heat stress relief, physiological and thermal comfort, ergonomic mobility, and other aspects of the HCW experience while wearing PPE. Working closely with standards bodies such as the Association for the Advancement of Medical Instrumentation (AAMI), the American Association of Textile Chemists and Colorists (AATCC), and ASTM International, McQuerry researches PPE performance. For example, she conducted research comparing the performance of reusable versus disposable surgical and isolation gowns and found that reusable gowns met AAMI performance requirements across 75 industrial laundering cycles, but disposable gowns did not meet requirements for water resistance or crosswise tensile strength even when new (McQuerry et al., 2021). She remarked on the need to generate more robust literature regarding comparative performance assessments of disposable versus reusable PPE. Additionally, research to maximize the thermal comfort of reusable gowns could address some of the concerns about reusable HCTs. McQuerry noted that potential mechanisms for improving reusable gown thermal comfort include technologies employed in other types of PPE or performance apparel, such as passive ventilation, and finishes with phase change materials or active cooling minerals.

Wearability and Garment-Based Wearable Technology

Lucy Dunne, professor and co-director of the Wearable Technology Lab at the University of Minnesota, researches functional clothing, electronic textiles (e-textiles), and garment-based wearable technologies. She stated the importance of a holistic consideration of functionality in designing PPE. The design process sometimes focuses on the core engineering objective of barrier resistance to the exclusion of user experience aspects of wearing PPE. Often, the success or failure of PPE is not related to its performance in a lab setting but rather to the user's willingness to wear it and to wear it appropriately. User willingness can be disrupted by aesthetics, comfort, and other human factors. Dunne underscored that perception and experience are not always aligned. For instance, mobility challenges while wearing a medical gown are often related to sizing and fit, and a person may assume a larger gown would be more mobile. However, this generally proves to be false, as extra fabric can impede

function when lowering one's arm, she explained. Another example is thermal balance and common perceptions that woven textiles are warmer than disposable ones. Dunne noted that this may be the case sometimes, but in other cases, the woven gown does not actually add to thermal load. Therefore, designers should differentiate what users perceive and what they experience and consider physics in assessing various options.

Manufacturing reusables is often slower and more expensive than manufacturing disposables, which creates an opportunity to produce a more complicated product, Dunne asserted. The drive to create the least expensive manufacturing method possible often compromises the design of the product. Given that reusable HCTs are already sewn by hand—a process that requires more time and expense than fully automated manufacturing—building in improved functionality may not substantially increase cost. The reusable PPE manufacturing process provides latitude to improve design to achieve increased usability in terms of mobility, sizing, fit, and thermal balance. Dunne added that some user factors, such as sizing, are connected to the entire infrastructure surrounding the product, which extends beyond manufacturing to the institution's ability to manage multiple sizes and create accessibility for people in need of those sizes at the time of need. As such issues are addressed, possibilities for the product expand. Likewise, the concept of functionality can broaden with the use of technology to create more advanced products. For instance, building electronics into PPE could enable integrated disinfection, active filtration, and detection of leaks, wear, and pathogens. Dunne remarked that because reusable PPE lasts longer and costs more than disposable counterparts, innovative technologies can be integrated into reusable products, whereas doing so would be prohibitively expensive for disposables.

Regulatory Perspective

Louise King, assistant professor and member of the Center for Bioethics at Harvard Medical School and surgeon at Brigham and Women's Hospital, uses her experience as a surgeon, researcher, ethicist, and lawyer to approach regulatory questions from the standpoint of single-use instruments. She noted that regulatory guidance for the decontamination and reusability of instruments is similar to that of medical gowns and other PPE. King highlighted ethical considerations of PPE, including ensuring the safety of HCWs and respecting clinicians through the provision of appropriate education and PPE options from which to choose within the context of the anticipated contamination risk. Additionally, environmental ethical concerns are at play, as hospitals are often among the largest contributors of waste in their communities. Balancing HCW and patient safety concerns with the health and safety of the environment is important, said King.

Discussion

Reusable HCT Regulations and Performance Standards

McCullough asked whether current regulations and performance specifications for reusable HCTs are adequate to protect HCWs in both routine and surge situations. Morgan replied that the updated ANSI/AAMI PB70:2022 standard, which also applies to disposable garments, creates new categories for "extended surgical gowns" and "decontamination gowns" (ANSI/AAMI, 2022). She remarked that gowns used in isolation rooms do not necessarily require liquid barrier protection; therefore, the option of a gown to protect against dry fomites without liquid barrier protection could be helpful to HCWs. Morgan expressed concern that some health care settings use unrated gowns. King replied that several federal regulations are in place to prevent such situations. An employee working in a hospital using unrated gowns could file a complaint with the Occupational Safety and Health Administration, and organizations found to be using unrated gowns face liability. Nevertheless, employees are not always aware of the protections in place and may be unfamiliar with the steps needed to ensure adherence to regulations, she added.

King commented that hospitals often do not account for the variety of interactions conducted by HCWs and may distribute PPE with the highest level of protection that could potentially be required, without allowing for nuance. Furthermore, many hospitals provide only rudimentary PPE training. Alternatively, hospitals could offer more PPE options and more in-depth training on selecting appropriate PPE, thereby allowing HCWs the freedom to make informed choices. Current regulations are adequate and align with evidence regarding the highest levels of protection needed, but protocols evolve as new evidence becomes available. King contended that rather than adding regulations, legislation or incentives are needed that motivate hospitals to explore educational opportunities and alternative methods of providing PPE to enable HCWs to make meaningful choices. McCullough added that PPE with the highest level of protection is not necessarily most functional for the person using it, and therefore it may not be the best option.

Referencing her research on firefighting PPE, McQuerry remarked that PPE approaches and perspectives from other industries can inform improvements in health care PPE. She noted that in her research, not only did disposable Levels 1 and 2 gowns fail to meet ANSI/AAMI PB70 requirements, but they are inadequate to accommodate different body shapes and sizes and how one typically moves while wearing the gown (McQuerry et al., 2021). McQuerry has found that standards

and performance requirements for fire service PPE are limited to the two-dimensional nature of fabric, and they do not address the three-dimensional PPE finished products worn on three-dimensional users. Although minimum requirements are in place for sizing and fit specifications of fire service garments, the standards do not fully consider functional design. For example, fabric for use in fire service has been over-engineered to the point that lack of breathability has increased thermal stress on users, which can be fatal. McQuerry argues that standardization for health care PPE should be balanced, without overstandardizing or overspecifying to the point of hampering functionality. She added that adopting certain voluntary specifications for HCTs as mandatory could address some of these issues.

Shirley highlighted the opportunity to improve post-market surveillance of PPE products, including solicitation of end-user feedback. Front-line workers have reported strikethrough, most often at the glove-sleeve interface, but it can be difficult to discern whether strikethrough is caused by a failure in performance or by user error. Improved post-market surveillance could lead to solutions for such issues. McCullough replied that such surveillance is the responsibility of manufacturers and could be considered from a regulatory standpoint. Beyond the 510(k) premarket submission to FDA, medical devices entail numerous implications for manufacturers, including establishment of a medical device quality system. She added that this should include post-market surveillance and suggested that regulatory considerations should extend beyond regulations that apply directly to the product to encompass the entire regulatory framework.

Education and Training Gaps

McCullough asked about education and training gaps related to risk assessment and PPE selection as well as steps that could increase the adaptability of reusable HCT programs. Morgan pondered whether any research has been conducted that assesses HCW ability to anticipate risk of exposure. Some procedures, services, and specialties carry higher exposure risk than others, such as turning patients in their beds or working with mental health or pediatric populations, she noted. However, HCWs may or may not anticipate which scenarios are more likely to entail splashing or spraying of fluids, leaning against contaminated surfaces, or holding patients contaminated with harmful substances. Additionally, PPE is often removed from its packaging before reaching HCWs; therefore, safety and use information is not readily available. Morgan asserted that ready access to PPE information should be provided by placing this information in the carts and cabinets from which HCWs take the items. Shirley remarked on an anecdotal understanding that a knowledge gap

exists among HCWs—and among infection preventionists and environmental health and safety professionals—about how to select the appropriate PPE for certain situations. Further research could clarify and identify such knowledge gaps. McQuerry commented that HCWs need training on how to wear PPE appropriately and why that is important. Her research with the fire service revealed that many female firefighters are unaware that women's gear is on the market. Increasing end-user awareness of the products currently available to them could enable professionals to locate options that are more functional for their bodies, she suggested.

King highlighted the need for educational efforts and legislative endeavors to support a shift from single-use products toward reusable products. Noting that the conversation around PPE typically focuses on safety, she suggested that environmental considerations should also be prioritized alongside protective effects. For example, legislation incentivizing environmental sustainability could enable progress toward dual goals of implementing PPE that keeps people safe and generates less waste. Educational efforts could then inform employees about the environmental benefits of reusable PPE. Given the substantial pressure on hospital leadership to keep people safe, she posited that incentives encouraging leadership to consider environmental effects could help to push reusable HCT programs forward.

Risks Associated with Reusable and Disposable Gowns

McCullough advised that equitable health care, diversity, and inclusion efforts should extend to HCW access to products that fit properly, as oversized or undersized garments can pose safety risks. She asked about the risks associated with both reusable and disposable gowns and how these influence user preferences. Dunne replied that differentiation often improves functionality, and a more customized size range can increase mobility. At the same time, adding options also increases the complexity of using the product, placing responsibility on users to determine which option fits best. She noted that this can have unexpected effects and result in user rejection of the product or a solution that meets one criterion while failing to meet others. Sometimes organizations faced with the need to train staff on how to select the most appropriate size instead opt to purchase only the largest size of PPE, requiring staff to make adjustments—such as using duct tape to gather excess material—that harm the core functionality of the product. The issue of engineering a sizing system and communicating that system to users and organizations is a design challenge that also applies to other forms of PPE, such as respirators. Morgan emphasized that wearing an oversized gown leads to additional grooves and creases that can hide contamination. Furthermore, the gown is likely

to sweep the floor when the user leans, stoops, or bends, thereby creating a safety hazard. Likewise, undersized gowns pose hazards; HCWs with large bodies or who are pregnant should not face difficulty in locating products that fit them. These aspects of fit affect end-user acceptance of a product, Morgan concluded.

McQuerry emphasized that in the 2018 study she conducted following media reports about strikethrough in a brand of gowns used in the 2014–2016 Ebola crisis, reusable gowns consistently outperformed disposable gowns (Cooper, 2016; McQuerry et al., 2021). After two brands of gowns were tested per level (for Levels 1, 2, and 3 gowns), the disposable gowns failed to meet ANSI/AAMI PB70, AATCC test method (TM) 42, and AATCC TM127 requirements for liquid barrier protection. The protection offered by reusable gowns held throughout the manufacturer recommended number of laundering cycles, said McQuerry.

In exploring the balance of risks and benefits of reusable PPE, Overcash and Sehulster co-authored an analysis of the risk for health care-associated infections (HAIs) associated with reusable HCTs (Overcash and Sehulster, 2022). Examining published records from the United States and the United Kingdom from the 1970s through the 2020s, they determined that 69 patients had HAIs attributed to the use of reusable PPE. To account for underreporting, Overcash and Sehulster made a conservative estimate that only 1 percent of HAIs related to reusable PPE were reported. Multiplying the 69 cases by 100 results in 6,900 reusable PPE–attributed HAI patients, which averages to 0.37 per day over the 50-year period. In comparison, approximately 5,500 cases of HAI occur within the United States or United Kingdom each day. The risk of HAI from reusables is approximately 1 in 15,000 (Overcash and Sehulster, 2022). Overcash emphasized that complete elimination of all risk of HAIs is not feasible, whereas understanding the true risk from HAIs faced by HCWs and patients resulting from use of reusable HCTs and implications of actions to reduce that risk in other areas is a practical path forward.

Technologies to Improve Reusable Gowns

Panelists were asked about the application or development of technologies to improve comfort, confidence in safety, efficacy, or any other aspect of reusable medical gowns. Dunne remarked that the COVID-19 pandemic sparked innovation and research in respirators, some of which translates to gowns. Active products can sense and, in some cases, respond to threats. For instance, adding an electrostatic charge to a garment could attract and trap particulates rather than allowing them to propagate through the room. Leak detection is potentially feasible, but it would require a network of electrodes attached to a removable device that would supply a current.

This network would detect moisture inside the barrier garment, whether from sweat or strikethrough. Gowns could potentially monitor whether the wearer is approaching heat stress or integrate accessory technologies, such as fans, to maintain a healthy thermal balance. Although such technology has not yet been tested, it could potentially improve functionality. She added that silver, which is antimicrobial, is currently used in thread to produce gowns with antimicrobial properties. McQuerry noted that zinc ion nylon fiber has antimicrobial properties from the time it is extruded and is therefore resistant to SARS-CoV-2 (McQuerry and Dodson, 2024). Furthermore, when used in face coverings, nylon reduces the clingy, damp sensation that some users perceive while wearing face coverings. McCullough remarked that thermal comfort can be a barrier to adoption of reusable gowns, so this technology could potentially increase uptake. Additionally, some of these technologies could improve PPE used in other industries.

Dunne explained that because the addition of smart systems generally increases the complexity and cost of products, these technologies give rise to issues of durability and reusability. Adding technology to disposable products is not feasible, while making products more durable creates opportunities to add technological innovations. Noting the tremendous textile waste generated by everyday clothing, she remarked that a universal design, in lieu of hundreds of individual models, could yield far-reaching benefits. Dunne acknowledged that adding materials needed for technological devices—such as silicone, metals, and semiconductors—to cotton or polyester garments generates disposal challenges by increasing the difficulty of recycling or composting the textiles. However, if such products are designed for durability and last a year longer than the original versions, this could potentially balance drawbacks with benefits.

Economic Considerations of Improved PPE Design

Replying to a question about the costs associated with increasing the comfort and protection offered by reusable PPE and whether health care organizations are willing to pay for it, Dunne remarked that numerous factors affect cost, such as the feature being added, how it is built into the gowns, and the relationships in place between the PPE manufacturers and the organizations using the PPE. She was optimistic about the feasibility of an incremental approach that begins with increasing the adoption of currently available reusable PPE products, then shifts to design improvements with various features over a span of time. Dunne remarked that she has worked in wearables and e-textiles for over 20 years, and she has learned that adoption is a slow, but not impossible process.

King stated that changing entrenched systems is expensive; thus switching to a reusable HCT program would likely be very expensive for

a health care system. Hospitals currently operate on tight budgets and rarely have incentives in place to promote such change. She reiterated the need for legislation that incentivizes sustainable practices in health care. Infrastructure for reusable PPE manufacturing is in place and innovators are developing improved products, but until the financial costs are offset, hospitals are unlikely to make an expensive change solely for environmental benefit, King remarked. McCullough noted that while technologies can overcome some barriers to reusable PPE adoption, cost is likely the biggest obstacle. She described the formidable challenge of convincing a health care facility with tight financial margins to make a large upfront investment in hopes of recouping future cost savings.

7

Decision-Making Support

The sixth session of the workshop featured a case study of a reusable isolation gown pilot program and outlined a decision-support framework that health care organizations could consider in exploring the incorporation of more reusable health care textiles (HCTs) into operations. Jacqueline Daley, senior director of infection prevention at Providence St. Joseph Health in Irvine, California, moderated the session and provided a brief overview of the decision-support framework for the adoption of reusable personal protective equipment (PPE). The framework features four categories—strategic analysis, tactical analysis, operations analysis, and impact assessment—and each category involves engagement with personnel from various areas of expertise (see Figure 7-1). Daley emphasized that using the framework requires a collaborative effort and added that the framework is intentionally generic to enable health care facilities to use organization-specific data within the categories.

CASE STUDY: DECISION PROCESS TO INCORPORATE MORE REUSABLE ISOLATION GOWNS IN HEALTH CARE OPERATIONS

Elizabeth Schenk, executive director of environmental stewardship at Providence Health, and Jack Holmberg, senior infection preventionist at Providence Health, described a reusable isolation gown pilot program implemented at a Providence Health medical center. They outlined the impetus for the program, a literature review, the pre-implementation process, rollout of the program, evaluation, and next steps. Schenk noted that Providence Health is a health system comprising 51 hospitals and 1,000

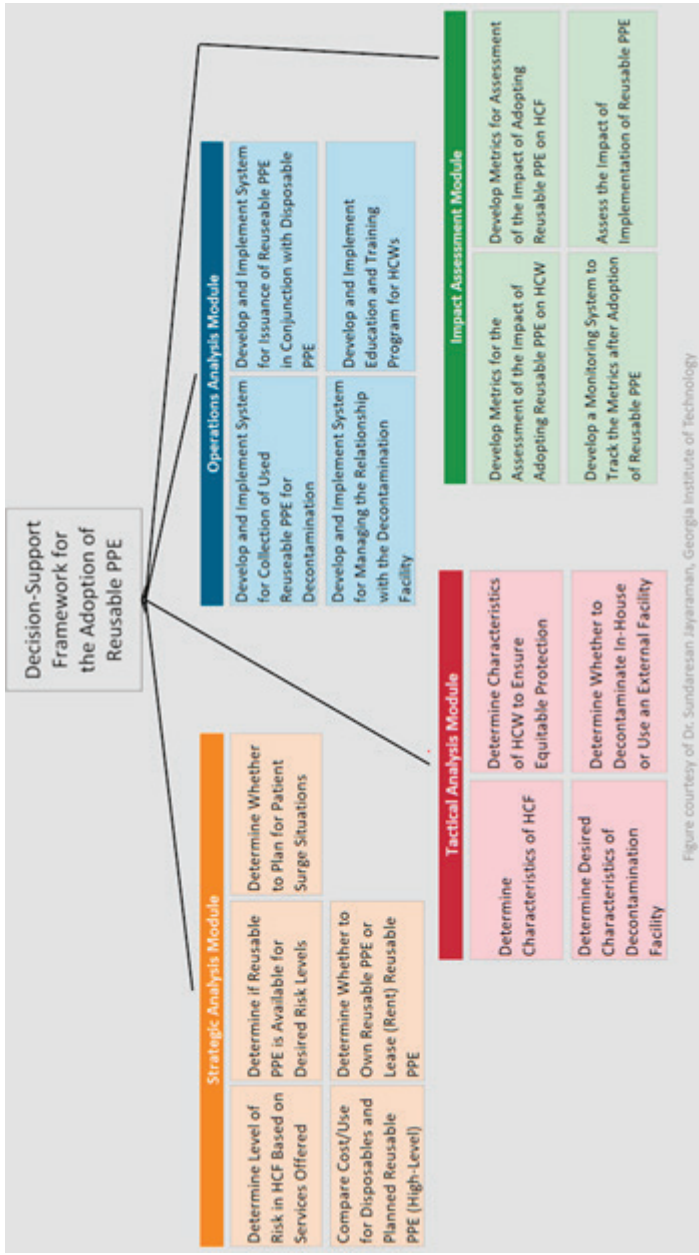

FIGURE 7-1 Decision-support framework for the adoption of reusable personal protective equipment.
NOTES: HCF = health care facility; HCW = health care worker; PPE = personal protective equipment.
SOURCE: Presented by Jacqueline Daley on March 5, 2024, at the Reusable HCTs for PPE Workshop. Figure created by Sundaresan Jayaraman for the workshop (unpublished).

clinics across seven western U.S. states. In recent years, Providence Health has made a commitment to driving environmental stewardship via three pillars: mitigation, adaptation, and advocacy. The mitigation pillar focuses on addressing drivers of pollution and climate change via waste optimization, energy and water efficiency, sustainable agriculture, reducing use of harmful chemicals, and decreasing carbon emissions. Providence Health established a goal of diverting more than 50 percent of its waste from landfills and hazardous waste treatment by 2030. The health system categorizes waste as disposed, diverted, or avoided. Disposed waste is sent to landfills or sent for treatment as hazardous or biohazardous waste. Diverted waste is composted, recycled, or donated, processes that generate value from waste and lower carbon output. Avoided waste applies to products eliminated from use, such as disposable PPE that is replaced with reusable HCTs. Schenk explained that in working toward increasing the proportions of diverted and avoided waste, Providence Health tracks and measures system changes and associated reductions in disposed waste.

Holmberg outlined the multidisciplinary process of implementing a reusable gown pilot program at Providence Willamette Falls Medical Center (PWFMC). He described that in 2020, the medical center ordered 39,000 reusable gowns in response to PPE shortages caused by the COVID-19 pandemic. Reusable gowns offer independence from supply chain fluctuations in addition to advantages such as waste reduction, carbon reduction, cost savings, comfort and breathability, durability, and fluid resistance. However, once available, there was a return to disposable gown use across many departments. To achieve the Providence Health sustainability goal of diverting and/or avoiding over 50 percent of its waste by 2030, PWFMC explored these advantages as part of a strategic analysis process to determine whether to implement an ongoing reusable gown program, said Holmberg.

Decision-Support Analyses and Assessment

The first step of the strategic analysis was performance of a literature review, which yielded a study by McQuerry et al. (2021) indicating that reusable gowns offer increased protection, substantial cost savings, superior breathability, and sustainability in comparison to disposable gowns, Holmberg stated. Furthermore, PWFMC already had decontamination and laundering processes in place, a consideration relevant to the tactical analysis and operations analysis. Evaluation of initial concerns led to questions regarding gown fluid resistance and comfort, ability to effectively clean the gowns, risk of health care-associated infection (HAIs), and whether shifting to reusable gowns constituted a process change. Examination of the reusable gown life cycle generated additional logistical questions, such as how a reusable HCT program at their facility would handle

gown delivery, collection, transportation, and tracking. Holmberg and colleagues learned that PWFMC Environmental Services (EVS) staff are responsible for delivering and stocking linens; therefore, a reusable HCT program would not burden managers with the responsibility of ordering gowns. Used gowns could be placed with regular laundry after doffing, and EVS and nursing staff would handle collection. After collecting soiled gowns, EVS would transport them to PWFMC's laundry co-op, where they would be washed at a minimum temperature of 160 degrees for 25 minutes to ensure effective cleaning. The specific reusable gowns used at PWFMC have a use life of 100 wash cycles and are tracked via scanning tags on the gowns. Holmberg added that the laundry co-op ensures gown integrity via inspections.

Pre-implementation and Implementation

Holmberg described the pre-implementation process, which involves conducting a risk assessment and providing executive leadership with the critical information in a format they are familiar with as a way to ensure that everyone is on the same page. Nursing and infection prevention professionals inspected the gowns and conducted a workflow walkthrough to provide feedback or concerns regarding donning and doffing procedures and the comfort and breathability of the gowns. Executive leadership then discussed and approved the reusable gown pilot program. This stage also involved initiation of ongoing evaluation of HAIs and numbers of isolation gowns used.

The pilot initially began in the intensive care unit (ICU) with 25 reusable gowns stocked daily by EVS. The donning and doffing procedures followed guidance from the Centers for Disease Control and Prevention, with the exception of adjusting the instruction to discard the removed gown into a waste container to placing it in a laundry bin (CDC, 2014). Given that the soiled reusable gowns are placed with the regular laundry, doffing procedures did not require a process change, although the units replaced open hampers with hampers with lids. He noted that PWFMC continued to make disposable gowns available for situations requiring transmission-based precautions (e.g., providing care to patients with fecal incontinence) as these patient interactions increase HCW risk of contact with infectious enteric agents and possible transmission (CDC, 2024; Louther, 1996). HCWs providing care to a patient with *Clostridioides difficile (C. diff)* or carbapenem-resistant *Enterobacterales* (CRE) and incontinence may feel more protected wearing a disposable gown, and PWFMC wants employees to feel safe while performing their duties.

Education about the program was communicated to HCWs via safety huddles, newsletters, email, and rounding. The 2022 rollout began in

the ICU before expanding to the medical/surgical unit, the emergency department, the labor and delivery unit, and ultimately to patient care areas within the entire medical center. Holmberg added that implementation in each unit was staggered by approximately a month to allow any issues or concerns to be addressed prior to further expansion.

Evaluation

After implementation, PWFMC conducted evaluation and impact assessment processes to identify any increases in HAI rates, calculate waste and cost reductions, and determine HCW satisfaction with the reusable gown program, said Holmberg. The HAI committee used 2021 HAI rates as a baseline for comparison with rates after the program was implemented in 2022. PWFMC had two cases of hospital-onset *C. diff* in 2021 and five cases in 2022, constituting a slight increase after the adoption of reusable gowns. However, the committee reviewed the 2022 cases and found some ordering inconsistencies. In 2023, PWFMC only identified one case of hospital-onset *C. diff*, and the committee concluded that the reusable gown program did not cause an increase of *C. diff* cases. In examining rates of catheter-associated urinary tract infections (CAUTIs), PWFMC had one case in 2021, two cases in 2022, and another two cases in 2023. Thus, the HAI committee did not identify a significant increase in CAUTI due to use of reusable gowns. Furthermore, Holmberg noted that an outbreak review found that no outbreaks involving respiratory or gastrointestinal pathogens such as COVID-19, influenza, or *C. diff* occurred in 2023.

Holmberg highlighted that an evaluation of overall waste reduction indicated a clear decrease from 2021 to 2023. In 2022, PWFMC laundry delivered 2,565 reusable gowns; this figure increased to 4,225 reusable gowns in 2023. Given that each gown can be laundered 100 times, fewer than 50 reusable gowns eliminated the need for 4,225 disposable gowns in one year. He outlined that PWFMC continues to use approximately 2,000 disposable gowns per week, resulting in consumption of 3,000 kilowatt hours of energy, 1,500 pounds of generated carbon dioxide emissions, 50 gallons of water, and 150 pounds of waste. Holmberg explained that in comparison with single-use isolation gowns, calculations indicate that use of reusable gowns decreases energy consumption by 30 percent, carbon dioxide emissions by 30 percent, water usage by 40 percent, and waste by 95 percent.

Potential Considerations and Next Steps

Holmberg acknowledged some disadvantages of reusable gowns. The gowns used at PWFMC, which are rated Level 2 by Association for

the Advancement of Medical Instrumentation (AAMI) standards, are not impervious to fluid barrier penetration. Therefore, PWFMC only uses the reusable isolation gowns as PPE for patient care and not for procedures. In contrast to some designs of disposable gowns that have tear-away closures for easy removal, reusable gowns do not break away, making the doffing procedure slightly more involved. He reiterated that disposable gowns may be preferred for contact enteric isolation or patients with fecal incontinence. After implementing the pilot program, a PWFMC policy update removed the wording "gowns are single use" to facilitate implementation of reusable gowns. An expanded literature review of recently published studies found support for reusable gowns and identified performance issues in disposable gowns (Davis and Haberland, 2023; Easter and Dabbain, 2023). Holmberg described the adoption of reusable gowns at PWFMC as a success, with next steps including potential regional expansion of the program and developing a standard operating procedure for reusable gowns at the regional and central division levels.

PANEL DISCUSSION

Health Care Systems' and Organizations' Perspectives

Skip Skivington, vice president of health care continuity and support services at Kaiser Permanente, provided the perspective from a large-scale health care system. He described the importance of PPE in protecting staff and patients during day-to-day operations and during surge events. He recalled that during the PPE supply shortage caused by the COVID-19 pandemic, standard procedures were not feasible, so the health center was forced to adapt practices based on available resources. His position entails planning for such surge scenarios. Barbara DeBaun, improvement advisor at Cynosure Health, offered a small-scale health care organization perspective. She began her career as an infection preventionist in 1978, before the HIV epidemic and COVID-19 pandemic. DeBaun remarked that over the decades, she has witnessed many HCWs compromise their safety by not wearing PPE appropriately when they perceive it to be uncomfortable or as impairing their ability to successfully complete a procedure. For example, HCWs sometimes snip the tips off their gloves if they are uncomfortable or seem to make it more difficult to start an intravenous (IV) line, and HCWs have poked holes in N95 respirators that feel too hot or cloying. She commented that safety expectations have changed since the 1970s, when HCWs wore short-sleeved gowns used by several HCWs over multiple days and hung on IV poles in between uses. Despite changes in safety protocols, PPE wearers may not comply with current PPE procedures if they are not involved in decision making and

do not understand the rationale behind procedures. Therefore, engaging users in PPE program planning is critical to the program's success, said DeBaun. Emphasizing the value of including users in planning, Daley noted one of her mantras, "nothing about me without me."

User Perspective

Katherine Townsend, professor at Nottingham Trent University, recalled working as a fashion designer and becoming aware of sustainability concerns and body issues related to mass fashion production, topics she explored in her practice-based doctoral thesis (Townsend, 2003). From 2015 to 2017, Townsend applied an approach she developed in her thesis to a project called Emotional Fit, a co-design engagement with a group of women who felt ignored by the fashion system. This project yielded a set of "emotionally durable" garment designs and a participatory methodology devised to explore and act on the physiological and psychological effects of clothing on the aging, changing, and active body. Such projects inform her current research on reusable PPE. During the COVID-19 pandemic, she learned of the lack of suitable isolation gowns and wrote a proposal entitled "Redesigning PPE: Enhancing the Comfort and Safety of Healthcare Workers Wearing Isolation Gowns to Treat Patients with COVID-19," which was granted funding by the Arts and Humanities Research Council (2024). Working with a team from Nottingham Trent University and the University of Maribor in collaboration with Anze Ltd., a surgical apparel manufacturer, and Revolution-ZERO,[1] a specialist in reusable HCTs who is developing modular decontamination hubs, Townsend researched and developed a reusable isolation gown system. Research methods included a review of procured gowns available to HCWs in local and national hospitals, interviews with clinical team leads, an illustrated online survey for HCWs, and wearer testing by nurses and surgeons in four National Health Service hospitals (Townsend et al., 2022). The research identified issues related to donning, doffing, poor fit, and thermal discomfort. Townsend and colleagues addressed these issues through reshaping, modifying fastenings and trims, and refabricating using a polyester carbon graft fabric with a high water-resistance level retained through a minimum of 100 wash cycles. She noted that UK legislation limits laundering of reusable PPE to 75 use cycles. Designed within a circular system that incorporates a take-back-and-repurpose scheme, the gowns will launch in 2024 (Townsend et al., 2023).

[1] Information about Anze Ltd is available at https://anze.co.uk/ (accessed May 7, 2024). Information about Revolution-ZERO is available at https://www.revolution-zero.com/ (accessed April 10, 2024).

Considerations in Application of the Decision-Support Framework for Adoption of Reusable PPE

Daley asked whether the common elements of the decision-support framework for the adoption of reusable PPE—strategic analysis, tactical analysis, operations analysis, and impact assessment—are sufficiently flexible and adaptive to apply to a range of health care settings, such as hospitals, clinics, and outpatient settings. Skivington stated that these elements are foundational and must be considered in implementing a reusable PPE program. Beyond these elements, large health systems must also consider regulations as they apply both in normal conditions and in emergency situations. Although regulations are rigid in terms of not allowing deviations from safety practices, the HCW alterations to PPE highlighted by DeBaun do occur. He remarked that he understands the desire for comfortable, mobile PPE, but altering PPE poses a safety risk and fails to comply with regulations, which can carry repercussions for the workplace. Patients are a health system's priority and when an HCW is not safe, neither is the patient, he emphasized. Given the ever-increasing costs of health care, health care systems work to limit costs to pass savings onto consumers. PPE is one of the drivers of health care costs, and while PPE is necessary, purchasing fewer options is beneficial from a cost perspective, said Skivington. Standardization is challenging and multiple factors may affect an HCW's willingness to use a PPE item, including rational or irrational bias against wearing it. The modernization of PPE could aid a health care system's ability to supply PPE that keeps HCWs and patients safe and that HCWs are willing to use. Numerous considerations should be factored into a decision to change a PPE program. Skivington remarked that although it is not feasible to please everyone all the time, a health system's goal is to keep everyone as safe as possible.

DeBaun underscored myriad human factors involved in the success of a reusable PPE program, noting that one size does not fit all, and heavier duty barrier protection is more appropriate for certain procedures than others. She remarked that operating rooms are kept at cool temperatures—despite cold patients having worse outcomes—because of the amount of PPE HCWs need to safely perform surgery. Surgical procedures often require a high level of barrier protection, and the lack of breathability can make users uncomfortably warm. In turn, this discomfort can pose a safety risk and operating rooms are therefore kept cold, said DeBaun. Describing her 15 years of clinical experience working in small rural hospitals and critical access hospitals (i.e., hospitals licensed for 25 or fewer beds), DeBaun stated that many small health care centers lack the infrastructure and buying power of large health care systems. Consequently, the factors that health systems consider as they

make decisions about PPE can vary depending on the size of the organization. DeBaun commented that the elements of the framework apply to systems of various sizes, but the application will look different for small versus large health care systems.

Emotional Fit Considerations of PPE

During the height of the COVID-19 pandemic, some HCWs wore double or triple layers of PPE, Daley recalled, noting the emotional aspects of the crisis. She asked Townsend about the aspects of "emotional fit" that systems should consider in making decisions about the PPE they supply to employees. Townsend described how emotive issues initially drew her to the research area of PPE design. Like all humans, HCWs come in all shapes and sizes, yet health systems may only supply employees with single-use PPE in one size. She noted that this was particularly true during the COVID-19 pandemic, and it created challenges for petite and larger nurses. Given that most nurses are female, with as many as 80 percent of nurses in the United Kingdom being women, attention to sizing challenges is usually directed at females. However, when she conducted a pilot program at a local hospital, the most petite nurse on staff was male. Townsend used this example to underscore the importance of being inclusive and avoiding making assumptions regarding size. She emphasized that this situation called for a more customized approach, noting that the line of PPE she has co-designed comes in sizes ranging from extra small to 5-extra-large. Townsend acknowledged that stocking a large variety of sizes can be cost prohibitive for smaller organizations. However, organizations should consider ordering the sizes they need for their current employees and shift the sizes ordered as needs and personnel change.

Townsend commended the PWFMC pilot program on incorporating training and opportunities to engage HCWs in the process. Too often, the voices of the people who wear HCTs are not heard when selecting HCTs, she maintained. The PPE shortage during the COVID-19 pandemic sparked outcry, but the issues went deeper than quantity, as many garments were not fit for purposes of the people who needed to wear them. Townsend echoed DeBaun's comments about how thermal comfort may impact an HCW's performance, noting that the stress of wearing PPE that does not appropriately offer coverage and mobility could likewise affect job performance.

Skivington highlighted the need to consider the specific employee population when supplying PPE. To illustrate, he described how an H1N1 surge caused a shortage of N95 respirators. California supplied N95 respirators from a state stockpile, but the majority of the fit tests failed. Criticism was directed at Kaiser Permanente for not properly training staff on how

to fit test, but this was unfounded, because fit testing is a daily process. An investigation revealed that the state had stockpiled N95 respirators designed for the construction industry, but the construction version is different from medical N95 respirators and was unfamiliar to HCWs.

HCW Engagement to Increase Adoption of Reusable Medical Gowns

Daley asked Schenk and Holmberg how they generated support to move the reusable gown pilot program forward. Holmberg highlighted the value of literature supporting the use of reusable HCTs. Additionally, a reusable gown program had previously been implemented in another Providence Health facility, providing traction for the PWFMC initiative. Efforts to engage HCWs before the rollout of the pilot program—such as conversations with nurse managers, bringing gowns to units for HCWs to try on, and soliciting feedback—seemed to lower resistance to the program. The HCW concerns included whether doffing gowns would require a new doffing location, the lack of a breakaway closure, and the gowns being harder to tie than disposable versions. As questions and concerns arose, Holmberg and his colleagues problem solved the challenges; this responsiveness to feedback generated clinical buy-in, which in turn strengthened the case made to leadership. Moreover, the pilot program began on a small scale, within a six-bed ICU unit, and the program solicited and responded to feedback before expanding to other units. This incremental approach allowed corrections and adjustments to be made in real time. Holmberg acknowledged that the slow rollout resulted in only 2,500 reusable gown uses in 6 months, slightly more than the 2,000 disposable gowns PWFMC uses per week, but he expressed optimism that building a foundation of support will benefit the program as it continues to expand.

Schenk highlighted an unpublished study conducted by Providence Health in November 2023, in which investigators surveyed 1,100 health professionals across all disciplines in the health care system using the Climate, Health, and Nursing Tool (CHANT), a tool to assess awareness, motivation, and behaviors related to climate change and health. The CHANT survey indicated substantial awareness about climate and health among HCWs at Providence Health; this awareness was coupled with concern and motivation to act, but few respondents were aware of the environmental stewardship initiative. Schenk attributed this to the difficulty in reaching all bedside HCWs in a large, complex health system, given how busy nurses are and the variance in their communication styles. She described the reusable gown program as aligning the commitment to prioritize patient safety with a growing commitment to the safety of the planet.

DeBaun stated her appreciation of the pilot program's incremental change approach that incorporates feedback from frontline staff. She recalled working during an Ebola epidemic and discovering that HCWs maintained the integrity of donning procedures, but doffing practices created opportunities for exposure to the deadly virus. She remarked that having people try on the gowns, practice tying and untying them, and providing feedback before they are asked to use them on the job could decrease the issues she saw with Ebola. Noting that she lives in San Francisco, where awareness of recycling and environmental practices is higher than in some parts of the country, DeBaun emphasized the diversity of levels of environmental awareness, which can present additional challenges to sustainability efforts. She stated that aligning safety of the patient, HCW, and the planet is a tremendous challenge facing health care.

Skivington remarked that Kaiser Permanente is a heavily unionized organization, and engaging labor during planning stages helps to accelerate change within their system. Developing union buy-in early on reinforces a commitment to frontline workers, thereby lowering potential for resistance. Townsend echoed the importance of engaging HCWs in handling and wearing reusable gowns ahead of implementation of a reusable HCT program. Involving management can facilitate this process, given how busy nurses are during shifts. She described difficulty in scheduling gown testing with two university hospitals in Nottingham and accruing feedback with two local hospitals in the East Midlands, which led to testing much farther away in South West England. Townsend remarked that although this travel was challenging, her team made the trip because of the value of expert feedback provided by nurses wearing the gowns. This expert feedback is integral to modifying the design of a product to work as well as possible for the end users, she added.

HCW Confidence and Compliance with PPE

The COVID-19 pandemic affected the spectrum of health care, including hospitals, acute care, teaching hospitals, critical access hospitals, and long-term care, said Daley. Given the various scenarios that may present in different settings, she asked about methods of ensuring HCW safety and reassuring staff that the supplied PPE is appropriate. Daley added that risk anticipation may be relevant, noting that anecdotal reports such as an HCW getting splashed in the eye during a procedure raises questions as to competency in anticipating risks. Holmberg suggested that the first step is to establish understanding of the rating of specific PPE and what that rating signifies. For example, the reusable gowns used at PWFMC have an AAMI Level 2 rating, which is equivalent to that of disposable gowns typically used at the health care center. Levels 3 and 4

gowns offer substantially more fluid resistance, but they are less breathable. The pilot program only implemented reusable gowns in areas where Level 2 gowns are appropriate for anticipated risk, thereby relieving HCWs of assessing risk in relation to reusable gown use. Given that direct patient care constitutes most of the gown usage, implementing reusable gowns for patient care offers balance to the continued use of disposable gowns for surgery and procedures at PWFMC. Holmberg noted that the hospital makes disposable gowns available on all units so that HCWs feel comfortable performing their duties, should they feel that a single-use gown is more appropriate for a given situation. Holmberg remarked that an education deficit leads to poor risk assessment; he highlighted the value of ongoing education and training in fostering staff accuracy in assessing risk. Townsend echoed that disposable PPE is appropriate in some situations and she advised taking an open, measured approach to increasing the use of reusable HCTs.

DeBaun described how long-term care settings operate under different recommendations than other health care settings. For instance, these recommendations advise HCWs to use enhanced barrier precautions for any high-contact duties, such as assisting a resident with bathing or toileting or providing care to a patient with a urinary catheter. She remarked that the recommendations specifically for long-term-care settings are contributing to an increase in the number of gowns used. Skivington commented that Kaiser Permanente has infection control committees that are rigorous in examining the risks involved in day-to-day hospital activities. The health system also has a national sourcing standards team that meets with the infection control committees monthly to discuss PPE product selection and to ensure that any updates or changes in standards are implemented. Each time a high-risk patient receives hospital care, Kaiser Permanente provides a detailed list of recommendations for the safe handling of the patient. He spotlighted high rates of compliance among HCWs, noting that ongoing education and reinforcement fosters compliance, especially when it includes explanations of why specific safety precautions are warranted. Skivington emphasized that the use of technology and design to improve the comfort of PPE would benefit HCWs and further increase compliance.

Schenk commented that HCW resistance to reprocessed equipment sometimes appears. She discussed a quality improvement project conducted at Providence hospitals to understand surgeon and perioperative staff resistance and barriers to using reprocessed materials and supplies, which revealed that providing HCWs with more knowledge and explanation reduced anxiety and addressed many of the participants' concerns. Educational efforts require data on outcomes, cost, and environmental effects such as carbon emissions. She remarked that HCWs may be less

concerned about the hospital saving money than they are about decreasing pollution. Therefore, metrics related to environmental effects should be incorporated into staff training and education.

Misperceptions Regarding Reusable and Disposable PPE

Daley commented on a common assumption that plastic is always more protective than cloth. Given that disposable and reusable gowns are rated with the same standards, she asked how this assumption can be changed. Skivington stated that people often have the perception that if a product comes straight from a package and has never been used, it is cleaner than a product that has been used and processed. Disposable products have attained a confidence level that reusable products have not. DeBaun remarked that many people believe that plastic provides better barrier protection than other materials regardless of whether evidence supports this belief. She added that some single-use gowns offer little barrier resistance, noting that such products were used during the COVID-19 pandemic when PPE shortages forced health care facilities to supply HCWs with any available PPE. The assumption that plastic is always protective is a dangerous misconception that needs to be dispelled, said DeBaun. Daley added that she received unfamiliar PPE during the COVID-19 pandemic, including a disposable gown with ties that attached in the center of the abdomen. She underscored that standards testing for barrier classification for isolation gowns does not extend to cuffs, hems, or bindings (e.g., ties), noting that the integrity of the garment could be compromised based on how these items are attached to the gown (e.g., stitched). This is particularly important when these are attached to areas where pressure commonly occurs, possibly leading to fluid penetration to the wearer's clothing and/or skin.

Holmberg commented that doctors and nurses respond to data. Recent studies indicate that the tensile strength and fluid resistance of disposable gowns are not as high as commonly presumed; they also indicate that reusable gowns do offer protection and safety. Sharing data with HCWs can increase confidence and acceptance of reusable HCTs. He remarked that as an infection preventionist, he understands that there is a stigma against reusable products and that shifting an entrenched assumption can be difficult. He approaches this assumption by drawing a comparison between reusable gowns and surgical instruments, which are reprocessed between uses. DeBaun emphasized the value of the PWFMC program evaluation infection reviews. She noted that data measuring the effects of a change can be profoundly influential, particularly in a data-driven field such as health care. Schenk added that many HCWs are concerned about the amount of plastic waste generated by the health care

industry and its contribution to microplastics pollution. Advancing the technology of PPE offers solutions for both safety needs and the issue of microplastics, she stated. Townsend remarked that education is needed to shift the perception that newness equates to protection. She underscored the importance of developing mechanisms to recycle and repurpose reusable gowns to divert them from landfills at the end of the life use cycle. Extending the utility of gowns into the post-use phase is the key method of reducing harm to the environment and fostering a "circular system," said Townsend.

PPE Demand Surge Considerations

Given that health care centers experience surges from causes ranging from infectious diseases to natural disasters to trauma from multivehicle crashes, Daley asked how to address surges in demand for PPE, noting that the PPE supply shortages early in the COVID-19 pandemic indicated a lack of pandemic preparedness. DeBaun replied that the COVID-19 pandemic supply shortages demonstrated that inadequate preparedness efforts provided a false sense of security. For instance, PPE supply stockpiles were not always kept up to date and, when the crisis hit, some stores of supplies had degraded and were no longer effective. The field of health care is much better at responding during a crisis than continually maintaining a state of preparedness, she maintained. Skivington added that when the COVID-19 pandemic disrupted supply chains, U.S. reliance on imported PPE contributed to supply shortages. He referenced a recent article highlighting that the investment made in domestic PPE production in response to the pandemic has evaporated and hospitals are once again purchasing PPE from foreign suppliers (Tita, 2024). Now that PPE is in ready supply and health care systems have established buffer stock, hospitals have returned to offshore purchasing. Skivington predicted that this dynamic will result in PPE shortages the next time a surge shifts the supply-and-demand curve. Daley commented on the importance of inventory management that involves a "first in, first out" cycle where the stockpile is continually used and replenished.

8

Aspects of Implementation

The seventh session of the workshop considered aspects of implementation of more reusable health care textiles (HCTs) within a health care organization, such as implementation strategies, systems and behavior change models, and barriers to adoption of reusable HCT programs. A panel discussion featured perspectives from health care system laundry services, sustainability in clinical care, personal protective equipment (PPE) use in health care settings, and the intersection of regulations and health care worker (HCW) safety. Jayaraman introduced and moderated the session. He remarked that health care executives determining whether to implement reusable PPE should consider various factors, including the risk level of the health care setting, facilitation of HCW safety and comfort, HCW training on appropriate donning and doffing procedures, space for the storage and disposal or laundering of PPE, waste reduction, ethical considerations, and financial aspects.

METHODS TO INCREASE ADOPTION OF REUSABLE HCTS

Jayaraman opened the discussion by asking panelists to share mechanisms to improve the adoption of reusable HCTs. Thurston spoke of the value of champions for reusable HCTs who have administrative support within an organization. A clinical educator, an appropriate committee, or another professional who understands the needs of HCWs who wear PPE can garner support for a reusable HCT program. King echoed the importance of champions to sustainability efforts, noting that a department chair at her hospital has been instrumental in raising awareness and

garnering collaborative support for various projects. She underscored the need for legislation that incentivizes sustainability in health care.

Several panelists spoke on the need to raise awareness regarding the safety and benefits of reusable HCTs. Cassandra L. Thiel, assistant professor at the New York University (NYU) Grossman School of Medicine and founder of Clinically Sustainable Consulting, highlighted that literature indicates that reusable HCTs are much less harmful to the environment than disposable products; thus, organizations working to reduce environmental footprints can do so via a reusable gown program. Edward McCauley, president and chief executive officer at United Hospital Services, a large cooperative laundry that serves over 70 hospitals and 850 clinics in Indianapolis, remarked that end-of-life, sustainability, and environmental studies support the use of reusable isolation gowns; he added that they offer economic cost savings over the life of the product. Noting that health care systems are typically the largest generators of pollution within their communities, King emphasized the importance of a including an ethical imperative to make changes that are beneficial to Earth and to community environments in the calculus of decision making. Thiel remarked that the COVID-19 pandemic revealed that reliance on single-use PPE made health care facilities vulnerable to supply shortages, whereas reusable gowns can increase supply resilience in times of a major crisis. McCauley noted that compliance with Association for the Advancement of Medical Instrumentation (AAMI) standards and consistent tracking of the number of times gowns are washed have alleviated health care provider concerns about the safety of reusable gowns.

REUSABLE HCT IMPLEMENTATION CONSIDERATIONS AND BARRIERS

Jayaraman asked about key factors in decision making and implementation strategy development for a reusable HCT program. Thurston highlighted the importance of contracting with a manufacturer that demonstrates the ability to supply and test PPE products to ensure that the PPE delivers the specified protection. She added that gowns must be laundered and decontaminated according to manufacturer recommendations and packaged in such a way that maintains cleanliness. The negotiated price of the product should be such that the total cost of the program—including transportation, laundering, and distribution of gowns—is within budget. In response to a question from Jayaraman about the procurement of PPE, Thurston described how Intermountain Health employs contract managers who oversee certain commodities and who work with buyers, contractors, and vendors to make deci-

sions regarding PPE and other equipment. A products committee meets biweekly to review new products under consideration for purchasing and to vet substitute products. This committee includes representatives from various service lines to engage a range of perspectives and, when more information is needed to reach a product choice, they consult with the Healthcare Laundry Accreditation Council (HLAC) or the Centers for Disease Control and Prevention (CDC).

Thurston also emphasized the need to garner support for reusable HCT programs from administration and through interdisciplinary teams, ensuring that key stakeholders' perspectives are heard, understood, and accounted for. Programs that use incremental rollout can learn from each unit as the program expands and adjust as needed to create successful change.

Logistical Barriers to Reusable HCT Program Implementation

In response to a question about barriers to implementation of a reusable gown program, Thurston remarked that because reusable HCTs are bulkier than disposable counterparts, space limitations for storage can hinder efforts to implement a reusable PPE program. Considering space requirements and problem solving before implementing a program can facilitate a smooth rollout. Thiel stated that despite the interest in reusable HCTs during the COVID-19 pandemic PPE supply shortage, she has been unable to successfully implement a reusable isolation gown program in the hospitals in which she has worked. Trial runs conducted at New York University (NYU) with cleaning staff—who are not directly involved in clinical care—did not gain traction for a continued reusable gown program. Storage space for reusable HCTs is a substantial barrier, particularly given NYU's Manhattan location, where square footage carries a high cost, said Thiel. McCauley echoed that reusable gowns are bulkier and require more storage space than disposable counterparts.

Morgan noted a challenge if reusable HCTs are not integrated into existing workflows. She stated that the infection preventionist at her hospital examined HCW procedures to determine how best to integrate reusable gowns into workflow. For example, the safest location to remove an isolation gown is at the exit of a patient room, but laundry bins may not be located near doors. The infection preventionist recommended that laundry bins be moved to align practice with proper doffing protocols.

Reusable Gown Design Considerations

Noting that reusable gown design could potentially increase the risk of contamination, Morgan emphasized the importance of training HCWs

on proper donning and doffing protocols and validating the safety of these protocols when implementing reusable PPE. She explained that a disposable gown with a breakaway closure can be removed simply by grabbing the material on one's upper arms and pulling downward. However, reusable gowns often have closures that must be untied, necessitating that the HCW reach up and behind the neck. A variety of factors such as hairstyle, arm length, and flexibility can increase the risk of contaminating oneself via contact with a contaminated sleeve or glove during this process. Morgan stated that she would like to conduct validation studies to determine whether HCWs are able to consistently doff reusable gowns without contaminating themselves. Thurston reiterated that the closures on reusable gowns can be difficult to tie and untie, complicating donning and doffing procedures. Design innovation could facilitate HCW ability to comply with proper protocols. As an example, Morgan noted that a small Velcro closure at the neck in the place of ties could replicate the tearaway closure that facilitates easy doffing and is featured on many disposable gowns. King remarked that a no-closure gown is easier to doff than ties or Velcro. This design features an extra panel that crosses around one's back and is secured by putting the left arm through a hole in the panel. McCauley replied that the three-armhole isolation gown on the market has a design that eliminates the contamination risk of struggling to untie neck closures.

A participant commented that laundry facilities have told PPE designers that their systems are unable to process three-armhole gowns and asked how design and laundry communities can collaborate to develop PPE that meets the needs of workers and adheres to laundering requirements. McCauley replied that United Hospital Services offers hospitals a range of style options. He added that the material used in three-armhole gowns is the same as that of other isolation gown designs, and therefore processing methods do not change. Thurston echoed that the laundering process is the same for both designs of gowns. However, economic considerations are perhaps at play, as the labor involved in presentation and finishing laundered gowns into packages could vary from one design to the other. Additionally, a laundry facility could be under contract with a certain vendor under terms that might not allow working with another vendor offering the three-armhole gown. She remarked that when Intermountain Health changes to a new product, the previous product is continued until all units reach end of life. Adding new designs to current offerings could provide HCWs safe, effective, and convenient options.

Morgan remarked that design features such as pockets can improve the usability of isolation gowns in enabling HCWs to place items from their lab coats into their gowns when they don PPE before entering a

patient room. She added that a large knit cuff on a reusable gown is undesirable because it can act as a sponge; she prefers gown cuffs that can be tucked under gloves. Such practical considerations could increase adoption of reusable gowns, said Morgan.

ETHICAL AND REGULATORY CONSIDERATIONS

In response to a question about the ethical, regulatory, and legal issues regarding gowns that face health care executives, King explained that ethics is about balancing the needs of identified stakeholders. The goal of reducing transmissible infection rates to zero is not feasible but aiming for as low a rate as possible benefits both HCWs and patients. Using reusable products can help strike a balance between safety needs and environmental needs, said King. She added that Occupational Safety and Health Administration (OSHA) regulations are stringent, and hospitals should comply with these regulations to obey the law and ensure safety. Thurston noted that in addition to OSHA regulations, health care systems and commercial laundry facilities should follow guidelines from other regulatory bodies such as The Joint Commission (TJC) and CDC. She remarked that the development of a recommended best practice for HCTs could enhance the ethical provision of PPE.

Thiel remarked that an additional ethical consideration is supporting local economies through circular supply chains using laundry facilities located near the health system. Given that employees in U.S. factories and facilities are protected by OSHA regulations, labor violations may be more common in overseas single-use supply chains. Reusable HCT programs thereby support workplace safety and U.S. job creation. Jayaraman asked whether the laundry industry is amenable to opening facilities in rural areas to enable local reusable gown supply chains. McCauley remarked that United Hospital Services is in Indianapolis, a city where several smaller laundry facilities have closed. Both commercial laundry facilities and hospital systems have trended toward becoming larger. He noted that some laundry facilities deliver to hospitals located 100 miles away, and delivery routes may include stops to smaller facilities along the way. United Hospital Services launders HCTs for 70 hospitals, 30 of which have 25 or fewer beds. Thus, some rural county hospitals are serviced by large corporate laundry facilities. King commented that a large laundry facility in Boston provides Mass General Brigham health care system with scrubs; this service could likely extend to reusable gowns. She remarked that in making shifts toward reusable materials, businesses that are not yet fully established within a service space would likely partner with health providers to expand service provision. Such partnerships simultaneously create jobs and improve environmental stewardship

within the communities in which health systems are located, representing a more ethical model than current reliance on disposable products.

Jayaraman asked how HCWs can be assured that the post-laundry inspection of reusable HCTs meets the requirements of performance standards. McCauley replied that a health care facility should ask the linen and laundry provider how they process isolation gowns and conduct inspections, noting that vague answers are cause for concern. Additionally, laundry providers should be able to describe their tracking processes to ensure that HCTs are not processed more times than indicated by the manufacturer, and they should conduct annual infection control tours. Thurston remarked that a health care system's infection preventionist should conduct an annual review and physical observation of the laundry facility. Furthermore, chemical vendors and textile providers can provide test pieces; Intermountain Health tests these on a quarterly basis. Thurston noted that hospital linen committees can raise safety concerns or questions. Accreditation visits, which involve a review of policies and practices, provide an opportunity to demonstrate documentation and policies ensuring that reusable gowns are appropriately cleaned and tracked.

TRAINING AND EDUCATION GAPS

Jayaraman asked about knowledge gaps related to HCW risk assessment, PPE selection, or other areas relevant to reusable HCTs. Morgan responded that most HCWs are not provided with PPE options; instead, they must use whatever is provided on an isolation cart or in the supply closet. Thus, HCWs depend on other people within the organization to make appropriate choices to ensure employee safety. She added that very few HCWs understand PPE ratings, testing, and options of levels that correspond with various duties. Instead, they make creative adjustments to the PPE they are provided. For instance, if an HCW is supplied with an unrated gown that does not offer sufficient fluid barrier resistance for a task such as rolling a patient, they might place a pad or towel between themselves and the body fluid before leaning against the bed. Morgan stated the value of teaching HCWs to examine the risks involved in their duties and helping them understand the tools available to them. An HCW, who will likely be exposed to fluids, may not be provided an AAMI Level 4 gown, but they may have access to a less protective gown and an underpad.

King remarked that she has become involved in sustainability efforts at her facility and evaluates opportunities to pare down the amount of equipment used in ORs. For example, equipment packets that are stocked for surgeons in the OR may include unnecessary items, and staff could be more intentional about only opening packages that will be used rather

than opening all provided packets before a procedure begins. Staff could engage with hospital leadership about the PPE and tools that are provided to help shift practices toward greater sustainability. Additionally, educational efforts can address the variety of equipment available, the purpose of each type of equipment, and HCWs' duties in using PPE appropriately and intentionally, said King.

Morgan noted that TJC will be issuing new requirements in summer 2024 that will encourage facilities to evaluate preparedness for infectious disease events, including training HCWs on appropriate PPE use. She remarked that health systems sometimes presume staff are competent in using PPE without assessing PPE use as a skill. She recalled that throughout her career, she was never tested on PPE competency until she provided care to patients with Ebola in 2014. Competency in consistently and correctly following PPE protocols should be reinforced much more heavily, said Morgan, referencing the hierarchy of controls for occupational health, where PPE is the last line of defense an HCW has against exposure to a hazard (NIOSH, 2023). She contended that appropriate use of PPE should be added to the competencies that hospitals already assess on an annual basis to verify HCWs' ability to comply with donning and doffing protocols.

Thurston commented that during the COVID-19 pandemic, some Intermountain Health employees were redeployed as safety officers. Trained by clinical educators and dressed in safety vests, the safety officers observed operations and provided immediate training in cases where protocols were not followed. The officers also conducted reviews and training in huddles to provide timely intervention to ensure safety during the crisis. For instance, a safety officer visited the laundry plant to verify that employees sorting soiled linen were correctly wearing N95 respirators, gowns, and gloves. Thurston remarked on the challenge of providing training when units are understaffed and overworked, and she found the safety officer model to be an innovative, time-sensitive solution. She added that this type of on-the-spot training enables immediate correction of behavior to prevent incorrect procedure from forming into habit. McCauley explained that health care laundries do not have the level of oversight that hospitals have. Approximately 15 years ago, HLAC led a self-governance effort to advance the practices and procedures within laundry facilities. More recently, TRSA issued the Hygienically Clean Healthcare Standard (TRSA, 2021). The American Reusable Textile Association (ARTA) hosts annual conferences and seminars on infection control, which provide education opportunities to laundry professionals to broaden understanding of considerations facing hospitals and HCWs.

Morgan remarked that a survey of infection preventionists revealed that a substantial portion were uncertain as to the level of gowns used at

their hospitals (Kilinc Balci, 2016). She stated her hope that the updated ANSI/AAMI PB70:2022 standard will address this knowledge gap (ANSI/AAMI, 2022). She commented that the term "reusable gown" may foster a misconception that gowns hung on hooks or door handles in rooms can be safely reused during a future visit without first being processed. An HCW may think a gown is uncontaminated and that wearing it again at some point in the future is frugal and responsible, but HCWs have no way of knowing whether a used gown is contaminated, Morgan emphasized. Therefore, the term "reusable" could inadvertently increase potential for cross-contamination and environmental contamination. Until updated terminology is adopted, education efforts should inform HCWs that a gown is only safely reusable after being laundered. King emphasized the need for more education on the conditions that require PPE to be placed in a biohazard bin and which items can appropriately be placed in the bin for recycling.

Jayaraman asked about financial considerations of training and whether any resistance to cost affects educational efforts. Thurston replied that Intermountain Health prioritizes safety and has invested in efforts such as establishing "do not disturb" zones to decrease distraction. Thurston underscored that training and safety efforts carry a cost, but the potential cost of employees contracting infections should also be considered.

LESSONS FROM SUSTAINABLE SYSTEMS

Highlighting research by Thiel indicating that the environmental footprint of surgical procedures completed at Aravind Eye Care System (AECS) in India was 5 percent the size of the same procedures performed in a UK hospital, Jayaraman asked about U.S. barriers to achieving the levels of environmental sustainability attained at AECS (Buchan et al., 2022). Thiel explained that the study focused on cataract surgery, one of the most common procedures in the world. To enable access to patients living in poverty, AECS designed a care structure with the goal of reducing the cost of cataract surgery. AECS has found that providing care at higher volumes lowers costs, both in terms of the cost for the patient and the per-patient overhead expenses for the provider. Reusable HCTs are also a driving force in reducing costs, yet the only disposable HCT used is a small single-base drape placed over the surgical area. The reusable cloth caps, masks, gowns, and scrubs worn by HCWs, as well as blankets and linens, are cleaned at laundry facilities located within AECS hospitals. On-site autoclaves sterilize any equipment requiring sterilization. Thiel remarked that the efficient system created at AECS involves a surgeon alternating between two patients during the procedures.

The U.S. health system could benefit from approaches that maximize efficiency, said Thiel. She noted that NYU is experimenting with performing bilateral cataract surgeries, in which new patients have a visit for preoperative testing and then an additional visit for surgery in both eyes. Thiel collaborates with EyeSustain, a global coalition of eye organizations and ophthalmologists working to implement sustainable ophthalmology practices worldwide.[1] This collaboration with EyeSustain coupled with grant funding from the National Eye Institute have enabled her exploration of legal barriers to adoption of sustainable practices. Health care providers often cite policy or regulation as the reason for current operating room (OR) practices that carry a larger environmental footprint than those utilized at AECS. However, examination of these matters often reveals that the practices do not pertain to firm governmental regulations or, in some cases, hospital policies. Most often, habituated practices have become part of the culture and internalized as "the way things are done" by staff, said Thiel.

King remarked that when visiting underresourced areas to donate surgical services, she has witnessed careful use of resources that includes launderable HCTs. These sustainable practices are compatible with safety, as demonstrated by infection rates at these facilities that are similar to or better than those at her home institution. She suggested that large health systems working to improve sustainability could incorporate the evidence-based practices used in underresourced areas as an initial step in shifting culture.

Cultural attitudes within a workplace yield substantial challenges for an engineer working to change a system, Thiel remarked, noting that her area of expertise is different from that of researchers who study change management. Typically, doctors carry forward the practices they learned during training into the next institutions in which they work. For instance, NYU offers preference cards to newly hired surgeons on which to list the supplies they want in the OR; surgeons tend to indicate that they want the equipment provided in the ORs at their previous institutions, she noted. Similarly, nursing staff tend to prefer practices learned during training or from one another that have become the norm, not necessarily because they are the best practices but because they are familiar. Thiel maintained that health systems could adopt a more sustainable approach by shifting focus from the preferred practices of individuals to institutional processes that are safe, effective, and sustainable. Over time, HCWs would grow accustomed to these new practices and become comfortable with them. Jayaraman reiterated that achieving the decreased environmental footprint of AECS would entail process redesign and culture change.

[1] More information about EyeSustain is available at eyesustain.org (accessed April 13, 2024).

9

Closing and Possible Paths Forward

The workshop closed with remarks from Jayaraman and from a leader of the sponsoring organization.

CONSIDERING PATHS FORWARD IN EXPLORING REUSABLE HCTS

Jayaraman highlighted key points from the workshop, including potential approaches to increase the adoption of reusable personal protective equipment (PPE) (see Box 9-1), and discussed possible paths forward in exploring reusable health care textiles (HCTs). He described the need to strike a balance in accounting for numerous factors when considering greater use of reusable HCTs. These factors include economics, environmental effects, and the safety of patients and health care workers (HCWs), which is of paramount concern and entails equitable protection. The One Health paradigm that considers the interconnected health of humans, animals, and the environment is relevant to achieving this balance, Jayaraman noted.

Jayaraman described ensuring the safety of HCWs and patients as paramount within a health care setting, with all other considerations being secondary. He remarked that a systems approach is essential when considering implementation of reusable HCTs. Therefore, efforts to increase the adoption of reusable HCTs should engage HCWs, procurement personnel, executives, and manufacturers and suppliers. A risk-based decision-support framework facilitates the exploration of

BOX 9-1
Potential Approaches to Increase the Adoption of Reusable Personal Protective Equipment Identified by Individual Speakers[a]

Innovation

- By updating manufacturing processes and implementing innovative tracking technology, the reusable health care textile (HCT) industry could increase reusable personal protective equipment (PPE) functionality and improve the tracking accuracy for HCT use life. (Merrow)
- Innovation in reusable HCTs could enable recyclable gowns made from recycled materials, thereby achieving a sustainable circular supply chain. (Merrow, Wintz)
- Increased automation and robotics in the reusable HCT industry could increase manufacturing efficiency and scalability, and decrease prices for reusable products. (Merrow, Wintz)
- Design features that could improve HCW safety and comfort in wearing reusable HCTs include: ease in donning and doffing; ability to fold flat; thermal comfort through passive ventilation or active cooling mineral finishes; integrated antimicrobial properties; electrostatic charge to trap particulates; and detection of leaks, wear, and pathogens. (Thurston, McQuerry, Dunne, Skivington, Morgan)

End-User Engagement

- Soliciting and incorporating end-user feedback into an iterative design process improves the user experience and could decrease resistance to adopting reusable HCTs. (Merrow)
- Soliciting and responding to input from a wide range of health care workers (HCWs) and engaging them in opportunities to sample various reusable PPE designs and participate in the selection process could foster enthusiasm in reusable HCT programs. (Marvel, DeBaun, Holmberg, Townsend)
- Physicians hold influence with hospital leaders, and collective requests for reusable HCT programs from groups of physicians have been successful in some cases. (Overcash)
- The Office of the U.S. Trade Representative is currently conducting engagement efforts with stakeholders to better understand how to support the domestic textile manufacturing base. (Agama)
- Engaging labor unions early in the process of adopting reusable HCTs reinforces a commitment to frontline workers and lowers potential for resistance. (Skivington)
- Champions of reusable HCT programs within health care systems are instrumental in generating openness to program adoption. (Thurston, King)

Cost Reduction

- Reducing the cost of biodegradable materials for PPE and demonstrating the performance of polymers made from renewable sources could drive demand for sustainable products. (Bhat)
- Investment in greater automation in HCT laundering and tracking reduces servicing costs and ensures that PPE retains its protective properties. (Thurston)

- Incentives are needed to encourage health care systems to purchase reusable HCTs. (Merrow, King)
- Underresourced health systems offer lessons in providing safe, effective services while generating less waste; data from such systems are instrumental in demonstrating efficacy of reusable HCT programs. (Thiel, King)

Education

- Product evaluation committees in hospitals and long-term care facilities are a mechanism for educating HCWs about reusable HCTs and generating buy-in for reusable PPE programs. (Falk)
- Canada has a higher rate of reusable HCT adoption than that in the United States; the successful efforts of Canadian commercial laundry facilities to highlight the merits of reusable HCT programs to customers could serve as an example to follow. (Petrovskis)
- National organizations could raise awareness of the economic and environmental benefits of reusable HCTs. (Thurston)
- Consumer education efforts within health care settings about the availability, safety, and benefits of reusable HCTs could increase adoption rates. (Agama, McQuerry, Schenk, Holmberg)
- Raising awareness that reusable gowns increase supply resilience during major health crises could encourage adoption of reusable HCTs. (Thiel)
- The development of best-practice standards could raise awareness of the safety and effectiveness of reusable HCTs. (Thurston)
- Comparing reusable HCTs to the use of reprocessed surgical instruments may facilitate HCW understanding that reusable medical supplies can be safe. (Holmberg)
- Infection evaluation of reusable HCT programs and laundering facility PPE performance testing provides reassurance to HCWs of the safety of these programs. (Holmberg, DeBaun, McCauley)
- Many HCWs and organizations are concerned about environmental sustainability; efforts to raise awareness about the environmental benefits of reusable HCTs could generate enthusiasm for these products. (Schenk, Thiel, King)

Reducing Logistical Barriers

- Addressing the barrier of group purchasing organizations' support for single-use products could increase purchasing of reusable HCTs. (Overcash)
- Addressing access and availability of appropriate laundering services could encourage widespread reusable HCT programs. (Shirley)
- The availability of disposable gowns alongside reusable HCTs may increase HCW comfort with—and thus, confidence in—a reusable HCT program. (Holmberg)
- An incremental approach to reusable HCT program rollout—which solicits and responds to feedback at each stage of scaling—facilitates problem solving and decreases resistance. (Holmberg)
- Integrating reusable HCTs into the established workflow increases HCW convenience in adhering to HCT protocols. (Morgan)

continued

BOX 9-1 Continued

- Providing gowns in sizes appropriate for current staff members can improve fit and encourage end-user acceptance of the product. (Morgan)
- Federal and state organizations could lead by example by purchasing products that are better for the environment and support U.S. manufacturing. (Merrow)
- Governmental efforts to foster PPE supply chain resilience for future crises and pandemics could bolster adoption of reusable HCTs. (Merrow)
- Legislated incentives for environmentally sustainable practices could foster adoption of reusable PPE. (King)

[a] This list is the rapporteurs' summary of points made by the individual speakers identified, and the statements have not been endorsed or verified by the National Academies of Sciences, Engineering, and Medicine. They are not intended to reflect a consensus among workshop participants.

technical, economic, environmental, logistical, regulatory, and education facets of implementing a reusable PPE program. He stated his optimism that adoption of reusable HCTs will increase—particularly given the higher levels of environmental awareness present in the new generation of HCWs—and this effort will contribute toward protecting the safety of people, animals, and the environment.

CLOSING REFLECTIONS

Maryann D'Alessandro, director of the National Personal Protective Technology Laboratory (NPPTL), offered final reflections and outlined next steps. Sponsored by the National Institute for Occupational Safety and Health (NIOSH), the workshop was designed to examine the feasibility and potential benefits of increased use of reusable PPE. The workshop will serve as input for a NIOSH report exploring the increased use of reusable PPE in health care while ensuring the safety and health of HCWs and patients. The NIOSH report will emphasize health care delivery that (1) is conducted in an environmentally sustainable manner, (2) is provided at a potential cost savings, and (3) catalyzes action in the space of reusable PPE. Outlining NPPTL responsibilities, she described conformity assessment goals to address PPE workplace needs. NPPTL is addressing the goal of reducing inhalation hazards through leadership in research, federal standards development, and respirator approval activities. Efforts toward the goals of reducing dermal hazards and reducing injury hazards are less extensive. Although NPPTL has established a robust research

portfolio and participates in consensus standards regarding these goals, the research center does not own the standards and does not certify PPE related to dermal and injury hazard reduction.

D'Alessandro remarked that this workshop catalyzed conversations to identify potential actions in several areas:

1. Research in innovative approaches toward understanding PPE performance, such as sensors and improved design for emotional fit;
2. Standards development activities to address important standards gaps, such as cleaning efficacy for hospital soils on gowns, procedures for reusable facepieces, and differentiation for the minimum performance properties between reusable and disposable gowns;
3. Identification of conformity assessment enhancements to ensure that products continue to conform to the requirements they claim by expanding postmarket activities and quality considerations; and
4. Efforts to develop and disseminate communications tools to support health care systems and individuals.

She stated that communication tools should be used before the purchase of reusable gowns, respirators, or other forms of reusable PPE. These tools could facilitate understanding of the exposures being addressed and the options available with possible consideration of a control banding approach based on risk. Recalling the example of respirator stockpiling performed without first determining whether the respirators would fit the intended population, D'Alessandro emphasized that steps should be taken to ensure that reusable PPE is acceptable to end users before purchasing. This workshop identified numerous factors to consider in these determinations.

Benefits and drawbacks are both associated with the use of disposable or reusable gowns in health care, said D'Alessandro (see Box 9-2). Increased use of reusable gowns presents opportunities for enhanced pandemic preparedness, reduced environmental impacts, and potential cost savings in terms of cost per use. However, gowns must provide appropriate barrier resistance and address end-user concerns regarding design and comfort; appropriate laundry services must also be available. D'Alessandro outlined that increasing the use of reusable isolation and surgical gowns in the U.S. health care system will require a multifaceted approach involving research and development, regulatory support, standardization and guidance, investment in education and awareness, and investment in infrastructure through incentives, legislation, and other approaches.

D'Alessandro explained that NIOSH will consider the information presented in the workshop and work to identify (1) actions that can be taken

BOX 9-2
Balancing Benefits and Drawbacks for Both Disposable and Reusable Personal Protective Equipment Identified by Individual Speakers[a]

Manufacturing

- Manufacturing reusable health care textiles (HCTs) is more labor-intensive—and therefore more expensive—than disposable personal protective equipment (PPE). (Merrow)
- Reusable HCT manufacturers contend with substantial compliance expenses related to performance testing and U.S. Food and Drug Administration fees. (Stull)
- Manufacturing of disposable PPE requires less workforce training than reusable HCTs and can therefore be scaled more quickly. However, reusable HCT manufacturers demonstrated scaling ability and the capacity to manufacture one million reusable gowns per week during the COVID-19 pandemic. (Merrow)
- Reusable HCTs are more labor-intensive to manufacture than disposable PPE, and the per-unit price and durability of reusable HCTs are higher than those of single-use products. These factors lend themselves to an iterative design process and the incorporation of user-desired design and technology features in reusable HCTs that is not feasible for disposable products. (Merrow, Dunne, King)
- Innovation could enable reusable gowns that feature electrostatic charge to trap particulates, monitor risk of heat stress, include fans or passive ventilation, and detect leaks, wear, and pathogens; such features are cost-prohibitive for disposable products. (Dunne)
- Domestic reusable HCT manufacturing provides economic support to U.S. communities and labor protections to workers that overseas disposable PPE manufacturing does not. (Merrow, Thiel, King)
- The disposable PPE supply chain is more vulnerable to disruption than the more circular reusable PPE supply chain. (Thurston, Agama)

Purchasing

- The range of sizes, shapes, and styles of disposable gowns is currently wider than for reusables. (Falk)
- Compared with disposable HCTs, reusable HCTs require larger upfront investment but yield accrued cost savings over time. (Merrow, Overcash, Agama, Holmberg)

Storage and Use

- Packaged disposable gowns are more compact than their reusable counterparts, requiring less space for storage. (Falk, Merrow, Morgan, Thurston, Thiel, McCauley)
- Reusable HCT wash cycles must be accurately tracked to ensure that PPE continues to offer adequate protection. (Falk, Shirley)
- Advancements in laundering technology have decreased the water, electricity, and gas required to appropriately process reusable HCTs. (Remillong)

- The risk of hospital-acquired infections (HAIs) associated with reusable HCTs is low, and transitioning from disposable to reusable HCTs does not increase HAIs. (Overcash, Holmberg)
- Reusable HCT programs enable recovery of inadvertently discarded medical equipment and personal items. (Overcash)
- The environmental benefits of reusable HCTs over disposable HCTs include decreases in greenhouse gas emissions, solid waste, and water and energy consumption. (Overcash, Marvel, Bhat, Holmberg)
- Disposable PPE entails a linear supply chain that depletes natural resources more quickly than reusable HCTs. (Bhat)
- The concern that reusable gowns are more uncomfortable to wear is not always based on experience; research suggests that HCWs prefer the comfort of reusable gowns to disposable ones. (Overcash, Holmberg)
- The term "reusable" may foster a misconception that gowns can safely be reused without first being processed. (Morgan)
- Laundering services for reusable HCTs are not available in all parts of the United States. (Shirley)
- Reusable gowns outperform disposable gowns for liquid barrier protection and crosswise tensile strength. (McQuerry, Holmberg)
- Reusable gowns can be more challenging to don and doff than disposable gowns. (Holmberg)
- Reusable gowns featuring tie closures at the neck are more difficult to doff than disposable gowns with breakaway closures, potentially heightening contamination risk. (Morgan)
- A common misconception that plastic always provides better barrier protection than reusable products can make HCWs vulnerable to risk exposure while wearing disposable PPE that does not perform as well as reusable PPE. (Wintz, Daley, Skivington, DeBaun, Holmberg)

End of Life

- The U.S. health care system generates 15,000 tons of waste from disposable PPE each day. (Agama)
- Radio-frequency identification tracking of reusable HCT wash cycles increases accuracy of use life monitoring, decreases labor requirements, and enables location tracking. (Remillong, Thurston)
- Disposable gowns are often unnecessarily treated as biohazardous waste, which involves greater cost and resource expenditures for transportation and disposal than general waste. (Marvel, Gibbs, Wright)
- Biodegradable, plant-based polymers are being developed that would enable a cradle-to-cradle reusable HCT supply chain in which medical gowns at the end of life cycle would be returned to raw material and re-manufactured into PPE. (Bhat, Dawson)

[a] This list is the rapporteurs' summary of points made by the individual speakers identified, and the statements have not been endorsed or verified by the National Academies of Sciences, Engineering, and Medicine. They are not intended to reflect a consensus among workshop participants.

now, (2) actions that require a 1- to 3-year time frame, and (3) long-term actions requiring more than 3 years. Long-term actions include research to address gaps identified in this workshop, such as gaps in standards and communication tools to address hazards confronting health care practitioners. By addressing such factors and implementing comprehensive strategies, increased use of reusable isolation and surgical gowns and reusable respirators could lead to benefits for health care providers and the environment. D'Alessandro stated that NIOSH will consider potential partners in this endeavor and seek to leverage the Allegheny Health Network elastomeric respirator case study and the Providence Health System isolation gown case study. She remarked that given that the term "reusable" could potentially generate confusion regarding the requirement that gowns should be appropriately processed between uses, terms such as "environmentally friendly," "green," or other descriptors should be considered.

Recalling that 1980s child passenger safety laws requiring children to wear seatbelts spurred change in seatbelt behaviors, D'Alessandro underscored that improved child safety might not have been realized in the absence of legislation. Similarly, the realization of the potential benefits of reusable PPE—such as reduced waste, decreased overall costs, and lowered environmental impact—is unlikely without legislation. NIOSH will work to identify partners to engage in advancing the effort to increase the use of reusable PPE. D'Alessandro closed by extending gratitude to the National Academies of Sciences, Engineering, and Medicine staff, the workshop planning committee, Jayaraman for his leadership in chairing the committee, and all speakers and panelists for their contributions to this effort.

Appendix A

References

AAMI (Association for the Advancement of Medical Instrumentation). 2023. *AAMI TIR12:2020/(R)2023. Designing, testing, and labeling medical devices intended for processing by health care facilities; a guide for device manufacturers.* Arlington, VA: AAMI.

AATCC (American Association of Textile Chemists and Colorists). 1945. *TM42 Test method for water resistance: Impact penetration*. Research Triangle Park, NC: AATCC. Revised 2017.

AATCC. 1946. *TM30: Antifungal activity, assessment on textile materials: Mildew and rot resistance of textile materials.* Research Triangle Park, NC. Revised 2017.

AATCC. 1949. *TM15: Colorfastness to perspiration*. Research Triangle Park, NC. Revised 2021.

AATCC. 1950. *TM61: Test method for colorfastness to laundering*. Research Triangle Park, NC. Editorially revised 2023.

AATCC. 1958. *TM90: Antibacterial activity: Agar plate.* Research Triangle Park, NC. Revised 2022.

AATCC. 1961. *TM100: Test method for antibacterial finishes on textile materials.* Research Triangle Park, NC. Revised 2019.

AATCC. 1962a. *TM104: Colorfastness to water spotting*. Research Triangle Park, NC. Editorially revised 2019.

AATCC. 1962b. *TM107: Colorfastness to water*. Research Triangle Park, NC. Revised 2023.

AATCC. 1968. *TM127: Test method for water resistance: Hydrostatic pressure.* Research Triangle Park, NC. Editorially revised 2019.

AATCC. 1970. *TM135: Dimensional changes of fabrics after home laundering.* Research Triangle Park, NC. Revised November 2018.

AATCC. 1976. *TM147: Antibacterial activity of textile materials: Parallel streak.* Research Triangle Park, NC. Editorially revised 2019 (with title change).

AATCC. 1977. *TM150: Dimensional changes of garments after home laundering.* Research Triangle Park, NC. Revised November 2018.

AATCC. 2000. *TM187: Dimensional changes of fabrics: Accelerated*. Research Triangle Park, NC. Revised 2013.

AATCC. 2020. *AATCC M14-2020 Guidance and considerations for general purpose textile face coverings*. Research Triangle Park, NC.

AATCC. 2021a. *TM211: Reduction of bacterial odor on antibacterial-treated textiles*. Research Triangle Park, NC.

AATCC. 2021b. *TM212: Fiber fragment release during home laundering*. Research Triangle Park, NC.

AATCC. 2024. *03024B: 2024 AATCC Manual of international test methods and procedures*, Vol. 99. Research Triangle Park, NC.

ALM (Association for Linen Management). 2020. *Interim guidance for processing single-use gowns in response to product shortages during COVID-19*. https://cdn.ymaws.com/www.almnet.org/resource/resmgr/document_library/ALMCOVID19ReprocessGownGuida.pdf (accessed March 25, 2024).

ANSI/AAMI (American National Standards Institute and Association for the Advancement of Medical Instrumentation). 2018. *ANSI/AAMI ST65: 2008 (R2018). Processing of reusable surgical textiles for use in health care facilities.* Arlington, VA: AAMI.

ANSI/AAMI. 2022. *ANSI/AAMI PB70:2022*. *Liquid barrier performance and classification of protective apparel and drapes intended for use in health care facilities.* Arlington, VA: AAMI.

Arts and Humanities Research Council. 2024. *Redesigning PPE: Enhancing the comfort and safety of healthcare workers wearing isolation gowns to treat patients with COVID-19*. https://pandemicandbeyond.exeter.ac.uk/case-studies/redesigning-ppe-enhancing-the-comfort-and-safety-of-healthcare-workers-wearing-isolation-gowns-to-treat-patients-with-covid-19/ (accessed April 10, 2024).

ASTM (American Society for Testing and Materials). 1995a. *ASTM F1670/F1670M-17a: Standard test method for resistance of materials used in protective clothing to penetration by synthetic blood*. West Conshohocken, PA. Revised 2024.

ASTM. 1995b. *ASTM F1671/F1671M-22: Standard test method for resistance of materials used in protective clothing to penetration by blood-borne pathogens using PHi-X174 bacteriophage penetration as a test system*. West Conshohocken, PA. Revised 2022.

ASTM. 2006. *ASTM F2407-20: Standard specification for surgical gowns intended for use in healthcare facilities*. West Conshohocken, PA. Revised 2022.

ASTM. 2019. *ASTM F3352/F3352M-23b: Standard specification for isolation gowns intended for use in healthcare facilities.* West Conshohocken, PA. Revised 2023.

Baracco, G., S. Eisert, A. Eagan, and L. Radonovich. 2015. Comparative cost of stockpiling various types of respiratory protective devices to protect the health care workforce during an influenza pandemic. *Disaster Med Public Health Prep* 9(3):313-318.

Buchan, J. C., C. L. Thiel, A. Steyn, J. Somner, R. Venkatesh, M. J. Burton, and J. Ramke. 2022. Addressing the environmental sustainability of eye health-care delivery: A scoping review. *Lancet Planet Health* 6(6):e524-e534.

CDC (Centers for Disease Control and Prevention). 2003. Background G. Laundry and bedding. In *Guidelines for environmental infection control in health-care facilities.* https://www.cdc.gov/infection-control/hcp/environmental-control/laundry-bedding.html (accessed May 29, 2024).

CDC. 2014. *Sequence for putting on personal protective equipment (PPE) and how to safely remove PPE*. https://www.cdc.gov/hai/pdfs/ppe/ppe-sequence.pdf (accessed April 8, 2024).

CDC. 2022. *CDC's core infection prevention and control practices for safe healthcare delivery in all settings*. https://www.cdc.gov/infection-control/hcp/core-practices/?CDC_AAref_Val=https://www.cdc.gov/infectioncontrol/guidelines/core-practices/index.html (accessed March 25, 2024).

CDC. 2024. *Transmission-based precautions*. https://www.cdc.gov/infection-control/hcp/basics/transmission-based-precautions.html?CDC_AAref_Val=https://www.cdc.gov/infectioncontrol/basics/transmission-based-precautions.html (accessed May 29, 2024).

Christensen, B. E., and R. P. Fagan. 2018. Chapter 18: Healthcare settings. In *The CDC Field Epidemiology Manual*, edited by S. A. Rasmussen and R. A. Goodman. https://www.cdc.gov/eis/field-epi-manual/chapters/Healthcare-Settings.html (accessed April 24, 2024).

Conrardy, J., M. Hillanbrand, S. Myers, and G. Nussbaum. 2010. Reducing medical waste. *AORN J* 91(6):711-721.

Cooper, A. 2016. *60 Minutes investigates medical gear sold during the Ebola crisis.* 49(47). https://www.cbsnews.com/news/60-minutes-investigates-medical-gear-sold-during-ebola-crisis/ (accessed April 5, 2024).

Davis, J., and K. Haberland. 2023. *The insidious dangers of disposable isolation gowns.* Paper presented at Association for Professionals in Infection Control and Epidemiology Annual Conference, Orlando, FL.

DOT (U.S. Department of Transportation). 2022. *Transporting infectious substances overview.* https://www.phmsa.dot.gov/transporting-infectious-substances/transporting-infectious-substances-overview (accessed May 6, 2024).

Duong, D. 2023. Improper disposal of medical waste costs health systems and the environment. *CMAJ* 195(14):E518-E519.

Easter, E., and S. Dabbain. 2023. An evaluation of the barrier and durability performance of reusable level 2 isolation gowns over their promoted service life. *AATCC J Res* 11(1):58-70.

Ellen MacArthur Foundation. n.d. *What is a circular economy?* https://www.ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview (accessed April 24, 2024).

EPA (U.S. Environmental Protection Agency). 2023. *What is a circular economy?* https://www.epa.gov/circulareconomy/what-circular-economy (accessed April 24, 2024).

European Parliament. 2023. *Circular economy: Definition, importance, and benefits.* https://www.europarl.europa.eu/topics/en/article/20151201STO05603/circular-economy-definition-importance-and-benefits.

FDA (U.S. Food and Drug Administration). 2015. *Premarket notification requirements concerning gowns intended for use in health care settings: Guidance for industry and food and drug administration staff*. https://www.fda.gov/media/92146/download (accessed March 22, 2024).

FDA. 2020. *Enforcement policy for gowns, other apparel, and gloves during the coronavirus disease (COVID-19) public health emergency: Guidance for industry and Food and Drug Administration staff*. https://www.regulations.gov/document/FDA-2020-D-1138-0023 (accessed March 22, 2024).

FDA. 2022. *Questions about personal protective equipment (PPE).* https://www.fda.gov/medical-devices/personal-protective-equipment-infection-control/questions-about-personal-protective-equipment-ppe (accessed April 24, 2024).

FDA. 2023. *Reprocessing of reusable medical devices*. https://www.fda.gov/medical-devices/products-and-medical-procedures/reprocessing-reusable-medical-devices (accessed April 30, 2024).

FDA. 2024. *Medical gowns*. https://www.fda.gov/medical-devices/personal-protective-equipment-infection-control/medical-gowns (accessed April 30, 2024).

Feber, D., A. Goel, D. Nordigarden, and S. Ponkshe. 2023. *Sustainability in packaging: US survey insights*. McKinsey & Company. https://www.mckinsey.com/industries/packaging-and-paper/our-insights/sustainability-in-packaging-us-survey-insights (accessed March 17, 2024).

Gartner, Inc. 2022. *Gartner survey finds 87% of business leaders expect to increase sustainability investment over the next two years.* https://www.gartner.com/en/newsroom/press-releases/2022-11-14-gartner-survey-finds-87-percent-of-business-leaders-expect-to-increase-sustainability-investment-over-the-next-two-years (accessed May 29, 2024).

Hanacek, N., J. Wang, and B. Hays. 2024. *NIST awards nearly $3 million for educational programs focused on circular economy to reduce plastic waste*. https://www.nist.gov/news-events/news/2024/03/nist-awards-nearly-3-million-educational-programs-focused-circular-economy (accessed April 24, 2024).

Harvard Business School. n.d. *The value chain*. https://www.isc.hbs.edu/strategy/business-strategy/Pages/the-value-chain.aspx (accessed April 24, 2024).

HLAC (Healthcare Laundry Accreditation Council). 2023. *HLAC accreditation standards for processing reusable textiles for use in healthcare facilities.* https://hlacnet.org/wp-content/uploads/2023/09/HLAC_AccreditationStandards_09-21-2023.pdf (accessed March 25, 2024).

Hines, S. E., S. Tai, J. German, H. Chen, M. Madden, E. Lulaj, C. Tong, M. Apte, S. Herman, and A. Birrell. 2020. Halo respirator assessment of reprocessing and cleaning (ARC). *J Int Soc Respir Prot* 37(1).

Hohenstein Laboratories. 2024. *Hohenstein hygienically clean for healthcare textile laundry management*. https://www.hohenstein.us/fileadmin/user_upload/Downloads_US/HO/Hohenstein_Hygienically_Clean_Standard_for_Healthcare_Textile_Laundry_Management.pdf (accessed March 25, 2024).

ISEA (International Safety Equipment Association). 2023a. *Benchmarking sustainability in the safety equipment industry.* Arlington, VA.

ISEA. 2023b. *Protecting workers and planet: Sustainability in the PPE and safety equipment industry.* Arlington, VA.

International Trade Administration. n.d. *Certifying your product with CE marking*. https://www.trade.gov/cemarking#:~:text=The%20CE%20marking%20(an%20acronym,requirements%2C%20which%20ensure%20consumer%20safety (accessed April 24, 2024).

Kilinc Balci, S. 2016. Isolation gowns in health care settings: Laboratory studies, regulations and standards, and potential barriers of gown selection and use. *Am J Infect Control* 44(1):104-111.

Landsman, G., M. Carey, A. McLane Kuster, G. Thompson, and M. Miller. 2023. Letter to Secretary Becerra, June 27, 2023. https://www.trsa.org/wp-content/uploads/2024/06/Letter-to-HHS-Secretary-Becerra-Requst-Study-on-Reusable-Health-Care-Textiles.pdf (accessed July 28, 2024).

Lawrence, C., D. A. Harnish, M. Sandoval-Powers, D. Mills, M. Bergman, and B. K. Heimbuch. 2017. Assessment of half-mask elastomeric respirator and powered air-purifying respirator reprocessing for an influenza pandemic. *Am J Infect Control* 45(12):1324-1330.

Louther, J. 1996. Enteric precautions for *Clostridium difficile*. *Am J Nurs* 96(4):19.

McLay, C. 2016. Chapter 113: Healthcare textile services. In *APIC Text Online,* edited by R. Dean and S. Popescu. https://text.apic.org/toc/infection-prevention-for-support-services-and-the-care-environment/healthcare-textile-services (accessed March 16, 2024).

McQuerry, M., E. Easter, and A. Cao. 2021. Disposable versus reusable medical gowns: A performance comparison. *Am J Infect Control* 49(5):563-570.

McQuerry, M., and A. Dodson. 2024. An antimicrobial zinc ion fiber for COVID-19 prevention in nonwoven face coverings for healthcare settings. *J Occup Environ Hyg* 21(4):239-246.

Micus, S., S. G. Rostami, M. Haupt, G. T. Gresser, M. A. Meghrazi, and L. Eskandarian. 2021. Integrating electronics to textiles by ultrasonic welding for cable-driven applications for smart textiles. *Materials Basel* 14(19):57-35.

Murakami, S., M. Oguchi, T. Tasaki, I. Daigo, and S. Hashimoto. 2010. Lifespan of commodities, part I. *J Ind Ecol* 14(4):598-612.

Nadeau, K. L. 2024. *The importance of healthcare value analysis: A comprehensive guide.* The Healthcare Hub. https://www.ghx.com/the-healthcare-hub/value-analysis-guide/ (accessed April 24, 2024).

NIOSH (National Institute for Occupational Safety and Health). 2020. *Considerations for selecting protective clothing used in healthcare for protection against microorganisms in blood and body fluids.* https://www.cdc.gov/niosh/npptl/topics/protectiveclothing/default.html (accessed March 25, 2024).

NIOSH. 2023. *Hierarchy of controls.* https://www.cdc.gov/niosh/hierarchy-of-controls/about/?CDC_AAref_Val=https://www.cdc.gov/niosh/topics/hierarchy/default.html (accessed April 24, 2024).

OSHA (Occupational Safety and Health Administration). 2019a. *Bloodborne pathogens and needlestick prevention.* https://www.osha.gov/bloodborne-pathogens/standards (accessed March 25, 2024).

OSHA. 2019b. *Personal protective equipment.* https://www.osha.gov/personal-protective-equipment/standards (accessed March 25, 2024).

OSHA. 2023. *Personal protective equipment.* 2023. https://www.osha.gov/sites/default/files/publications/osha3151.pdf (accessed May 29, 2024).

Overcash, M. R., and L. M. Sehulster. 2022. Estimated incidence rate of healthcare-associated infections (HAIs) linked to laundered reusable healthcare textiles (HCTs) in the United States and United Kingdom over a 50-year period: Do the data support the efficacy of approved laundry practices? *Infect Control Hosp Epidemiol* 43(10):1510-1512.

Pigott, P. 2021. *Plastic pollution: Could recycling PPE reduce the problem?* https://www.bbc.com/news/uk-wales-57687261 (accessed March 17, 2024).

Ping, W. 2011. *A brief history of standards and standardization organizations: A Chinese perspective*. East-West Center Working Papers.

Practice Greenhealth. 2023. *Sustainability benchmark data.* https://practicegreenhealth.org/sites/default/files/2024-01/2023-benchmark-data.pdf (accessed March 17, 2024).

RIT (Rochester Institute of Technology). 2020. *What is life cycle assessment (LCA)?* https://www.rit.edu/sustainabilityinstitute/blog/what-life-cycle-assessment-lca (accessed April 24, 2024).

Ruiz, C., S. T. Kenny, T. Narancic, R. Babu, and K. O. Connor. 2019. Conversion of waste cooking oil into medium chain polyhydroxyalkanoates in a high cell density fermentation. *J Biotechnol* 306:9-15.

Shah, A., E. Zhuang, J. German, S. Tai, M. Schanz, G. Glendening, M. Mason, O. Kolesnik, and S. E. Hines. 2023. Surface contamination of reusable respirators and face shields during care of critically ill COVID-19 patients. *Workplace Health Saf* 71(3):137-143.

Siegel J. D., E. Rhinehart, M. Jackson, L. Chiarello, and the Healthcare Infection Control Practices Advisory Committee. 2007. *2007 Guideline for isolation precautions: Preventing transmission of infectious agents in healthcare settings*. Centers for Disease Control and Prevention. https://www.cdc.gov/infectioncontrol/pdf/guidelines/Isolation-guidelines-H.pdf (accessed March 23, 2024).

Sun, G. 2011. Disposable and reusable medical textiles. Pp. 125-135 in *Textiles for hygiene and infection control*, edited by B. J. McCarthy. Woodhead Publishing.

Thomas, E. J. 2020. The harms of promoting "Zero Harm." *BMJ Qual Saf* 29(1):4-6.

Tita, B. 2024. The U.S. invested millions to produce masks at home. Now nobody's buying. *The Wall Street Journal*. www.wsj.com/health/healthcare/the-u-s-invested-millions-to-produce-masks-at-home-now-nobodys-buying-fee1c49f (accessed February 4, 2024).

Townsend, K. 2003. *Transforming shape: A simultaneous approach to the body, cloth and print for textile and garment design (synthesising CAD with manual methods).* Ph.D. thesis, Nottingham Trent University. https://irep.ntu.ac.uk/id/eprint/7552/1/7552_a482_Townsend.pdf (accessed May 29, 2024).

Townsend, K., S. Sterman, E. Salter, and K. Harrigan. 2022. *Out of isolation: Designing reusable PPE gowns based on an understanding of healthcare workers' lived experiences*. Paper presented at Design Research Society. Bilbao, Spain.

Townsend, K., T. Dawson, E. Salter, K. Harrigan, and S. Šterman. 2023. *Squaring the circle on PPE: A systemic approach to designing and repurposing gowns.* In K. Niinimäki and K. Cura, eds., *Proceedings, 5th PLATE Conference, Espoo, Finland*, edited by K. Niinimäki and K. Cura.. https://urn.fi/URN:ISBN:978-952-64-1367-9 (accessed June 12, 2024).

TRSA (Textile Rental Services Association). 2021. *Standard for producing hygienically clean reusable textiles for use in the healthcare industry.* https://hygienicallyclean.org/wp-content/uploads/2021/01/HCH_Standard_011421.pdf (accessed March 25, 2024).

Vozzola, E., M. Overcash, and E. Griffing. 2018a. Environmental considerations in the selection of isolation gowns: A life cycle assessment of reusable and disposable alternatives. *Am J Infect Control* 46(8):881-886.

Vozzola, E., M. Overcash, and E. Griffing. 2018b. Life cycle assessment of reusable and disposable cleanroom coveralls. *PDA J Pharm Sci Technol* 72(3):236-248.

Vozzola, E., M. Overcash, and E. Griffing. 2020. An environmental analysis of reusable and disposable surgical gowns. *AORN J* 111(3):315-325.

Appendix B

Key Terminology and Definitions Shared with Workshop Participants

- **Circular Economy/Circularity:** A system where materials never become waste, the life of the product is extended, and nature is regenerated. In a circular economy, products and materials are kept in circulation through processes such as maintenance, reuse, refurbishment, remanufacture, recycling, and composting. The circular economy tackles climate change and other global challenges, such as biodiversity loss, waste, and pollution, by decoupling economic activity from the consumption of finite resources (Ellen MacArthur Foundation, n.d.; EPA, 2023; European Parliament, 2023).
- **Health Care Setting or Facility:** Places where a broad array of health care services occurs, including acute care hospitals, urgent care centers, rehabilitation centers, nursing homes and other long-term-care facilities, specialized outpatient services, and outpatient surgery centers (Christensen and Fagan, 2018).
- **Health Care Textiles (HCTs):** Fabric-based products that touch patients and employees directly or indirectly on a daily basis in a health care setting (CDC, 2003; McLay, 2016).
    - **Disposable HCTs:** Generally, serve only as single-use products in health care facilities and many other institutional protective clothing applications for a given length of time. In some cases, these HCTs can be disposed of as commercial or regulated medical waste. However, in cases of contamination with infectious materials, these HCTs will be discarded as infectious waste (CDC, 2003; DOT, 2022).

  - **Reusable HCTs:** Designed to be repeatedly used in health care facilities. After each usage, the textiles should be laundered following the CDC's guidelines. When laundered, the used textiles are not only cleaned but also disinfected with bleaching agents such as diluted sodium hypochlorite solution or concentrated hydrogen peroxide solution (CDC, 2003). NOTE: While the workshop included discussion of reusable respirators, these are not reusable HCTs.
- **Health Care Worker:** Any individuals working within a health care setting who would need to use health care PPE or come into direct contact with health care PPE.
- **Life-Cycle Analysis (LCA):** A systematic analysis of environmental impact over the course of the entire life cycle of a product, material, process, or other measurable activity. LCA models the environmental implications of the many interacting systems that make up industrial production (RIT, 2020).
- **Lifespan:** Time interval from when a product is sold to when it is discarded (Murakami et al., 2010).
- **Medical Gown:** A type of personal protective equipment used in health care settings that can cover the entire middle of the body (back and front) from top of shoulders to knees and the arms to the wrist. The requirements for the design and construction of different medical gowns are based on the anticipated location and degree of liquid contact, given the expected conditions of use. (FDA, 2024; NIOSH, 2020).
  - **Isolation Gown:** A type of medical gown designed to isolate as much of the wearer as possible from exposure/contact with blood, body fluids, and other potentially infectious materials. The entire isolation gown, including the seams, but excluding the cuffs, hems, and bindings, must achieve claimed barrier performance (NIOSH, 2020).
  - **Surgical Gown:** A type of medical gown designed to primarily isolate the wearer's front and arms from exposure/contact with blood, body fluids, and other potentially infectious materials (NIOSH, 2020).
- **Personal Protective Equipment (PPE):** Equipment worn to minimize exposure to a variety of hazards. Examples include gowns, gloves, foot protection, face and eye protection, protective hearing devices (earplugs, muffs), hard hats, respirators, and full-body suits (OSHA, 2023).
  - **Health Care PPE:** PPE designed to protect the wearer from injury or the spread of infection or illness in health care set-

tings. Examples include gowns, gloves, face and eye protection, respirators, and full-body suits (FDA, 2022).
    - **Disposable PPE:** PPE designed to be used only one time and by one person prior to disposal (Sun, 2011).
    - **Reusable PPE:** PPE designed to be reused and able to withstand numerous cleanings, decontaminations, launderings, and sterilizations. For the purposes of this workshop, the planning committee considered the following items to be included as reusable PPE for health care: isolation gowns, surgical gowns, reusable elastomeric half-mask respirators (EHMRs) (Sun, 2011). NOTE: While the workshop included discussion of reusable EHMRS and other reusable respirators, these are not reusable HCTs.
- **(Re)Processing:** A detailed, multistep process to clean and then disinfect or sterilize reusable medical devices including reusable PPE and reusable HCTs (FDA, 2023).
- **Standards Organizations:** Organizations whose primary function is developing, coordinating, promulgating, revising, amending, reissuing, interpreting, or otherwise contributing to the usefulness of technical standards (Ping, 2011). Common standards organizations involved in PPE and HCT standards include the Association for the Advancement of Medical Instrumentation, American Association of Textile Chemists and Colorists, American National Standards Institute, and ASTM International.
- **Value Analysis:** Evidenced-based, systematic approach to review health care products, equipment, technology, and services. Using recognized practices, organizational resources collaborate to evaluate clinical efficacy, appropriate use, and safety for the greatest financial value (Nadeau, 2024).
- **Value Chain:** An analytical way to disaggregate a company into its strategically relevant activities in order to focus on the sources of competitive advantage, that is, the specific activities that result in higher prices or lower costs (Harvard Business School, n.d.).

Appendix C

Workshop Agenda

Health and Medicine Division
Board on Health Sciences Policy

Reusable Health Care Textiles for Personal Protective Equipment

Virtual Workshop

WORKSHOP AGENDA

March 4–5, 2024

Workshop Objectives: Workshop discussants and participants will have the opportunity to examine opportunities to increase the use of reusable health care textiles (HCTs) for personal protective equipment (PPE) used in health care settings. This workshop will provide the opportunity to exchange knowledge and ideas among key value holders—including technical experts, policy makers, manufacturers, and PPE users in health care—and to explore the potential benefits and feasibility of integrating more reusable HCTs into health care operations.

The public workshop will feature invited presentations and discussions to:

- Examine existing recommendations, approaches, and guidelines relating to reusable HCTs to ensure optimal protection of patients and health care workers;

- Discuss issues related to contamination of textiles and fabrics in health care facilities;
- Explore issues associated with current product and technology standards for reusable HCTs, considering input on standards needs from a past National Institute for Occupational Safety and Health (NIOSH) Personal Protective Technologies (PPT) Centers of Excellence Federal Register Notice;
- Examine the comparative performance, comfort, environmental impact, and use issues for disposable and reusable HCTs;
- Highlight similarities and differences between U.S. and European systems for reusable HCT use/maintenance/disposal systems, sustainability, and standards/regulations;
- Explore potential benefits, including potential cost savings, and feasibility issues related to increasing the use of reusable HCTs in crisis and everyday situations and in different health care settings;
- Discuss opportunities and approaches to integrate more reusable HCTs into health care operations where appropriate.

To watch the livestream, please visit the workshop's event page at https://www.nationalacademies.org/event/41729_03-2024_reusable-health-care-textiles-for-personal-protective-equipment-a-workshop.

DAY 1 – MONDAY, MARCH 4, 2024

Welcome and Overview of the Workshop

10:00 am **Chair Welcome and Opening Remarks**
Sundaresan Jayaraman, Workshop Chair

10:15 am **National Personal Protective Technology Laboratory (NPPTL) Opening Remarks**
Adam Smith, Senior Scientist, NPPTL

Session 1 Level Setting: The U.S. Ecosystem

10:30 am **Introduction**
Elizabeth Easter, Professor, University of Kentucky

This panel will lay the foundation of the workshop by defining key terms and concepts. It will describe the current U.S. ecosystems for disposable and reusable health care textiles (HCTs) for personal protective equipment (PPE).

10:40 am **Panel Presentations**
Elizabeth Easter, Panel Moderator

Overview of Disposable PPE Life Cycle
- *Charlie Merrow,* CEO, Merrow Manufacturing

Overview of Reusable PPE Life Cycle
- *John Wintz,* Group Vice President, Standard Textiles

Sustainability in PPE Manufacturers and Suppliers
- *Dan Glucksman,* Senior Director for Policy, International Safety Equipment Association (ISEA)

Health Care Worker Perspective on PPE Selection
- *Pamela Falk,* Epidemiologist, Association for Professionals in Infection Control and Epidemiology (APIC)

Audience Q&A *(time permitting)*

11:30 am **BREAK**

Session 2 Level Setting: Policies and Standards

11:45 am **Introduction**
Elizabeth Beam, Associate Professor, University of Nebraska Medical Center College of Nursing

This panel will lay the foundation of the workshop by defining key terms and concepts. It will describe the current policy and standards that influence the ecosystems for disposable and reusable PPE.

11:50 am **Panel Presentations**
Elizabeth Beam, Panel Moderator

Policies and Standards for Manufacturers
- ***PPE Manufacturers:***
  Jeff Stull, President, International Personal Protection; Member, ASTM Committee on Standards for Medical Face Masks and Protective Clothing

- ***Textile Manufacturers:***
  Erika Simmons, Technical Director, American Association of Textile Chemists and Colorists (AATCC)

Policies and Guidance for Use

- ***Federal Perspective:***
  Lynne Sehulster, CDC Division of Healthcare Quality Promotion (ret.)

- ***Health Care Perspective:***
  Tiffany Wiksten, Associate Director, Standards Interpretation Group, The Joint Commission

- ***Laundry and Reuse Perspective:***
  Liz Remillong, Division Vice President, Crothall Healthcare

Comparison of U.S. and International Policies and Standards

- *Henk Vanhoutte*, Secretary General, European Safety Federation

Audience Q&A *(time permitting)*

1:00 pm **BREAK**

Session 3 Environmental Impact

2:00 pm **Introduction**
Kelly Wright, Director of Minimally Invasive Gynecological Surgery and Associate Professor of Obstetrics and Gynecology, Cedars-Sinai Medical Center

This session is the first of a series aimed at characterizing the impact associated with the increased adoption of reusable versus disposable HCTs within health care settings. Specifically, this session will examine the environmental impact, both risks and benefits, using a life-cycle analysis (LCA).

2:05 pm **Presentation**
Environmental Impacts at Each Life Cycle Stage
Michael Overcash, CEO, Environmental Genome Initiative

2:15 pm **Case Study**
Environmental Sustainability in Clinical Care
James Marvel, Clinical Assistant Professor, Stanford University School of Medicine

2:25 pm **Panel Discussion**
Kelly Wright, Panel Moderator

Production and Use
- ***Biodegradable, Disposable PPE:***
  Gajanan Bhat, Professor, University of Georgia

- ***Reusable PPE:***
  Shelley Petrovskis, Director of Marketing & Regulatory Affairs, Lac-Mac Limited

Transportation of Disposable and Reusable PPE
- *Shawn Gibbs,* Dean, Texas A&M School of Public Health

End-of Life: Disposal and Recycling
- *Melissa Dawson*, Associate Professor, Rochester Institute of Technology

3:10 pm **Audience Q&A**

Session 4 Economic Impact

3:15 pm **Introduction**
Barbara Strain, Principal, Barbara Strain Consulting, LLC

In this next session of the series, the panel will examine the economic impact of the increasing use of reusable versus disposable HCTs. It will focus on both the short- and long-term infrastructure investments for health care facilities and value holders.

3:20 pm **Presentation**
Value Analysis 101
Barbara Strain, Principal, Barbara Strain Consulting LLC

3:30 pm **Case Study**
Costs Associated with Stockpiling of Reusable Respiratory Protective Devices
Gio Baracco, Professor, University of Miami

3:40 pm **Panel Discussion**
Barbara Strain, Panel Moderator

Production, Use, End of Life: Disposable and Reusable PPE
- *Charlie Merrow,* CEO, Merrow Manufacturing

U.S. Trade Policy
- *Laurie-Ann Agama,* Acting Assistant Trade Representative for Textiles, U.S. Trade Representative

Health Care System Perspective
- *Laura Thurston,* Director Laundry Services, Intermountain Health

4:15 pm **Audience Q&A**

Day 1 Wrap-Up

4:20 pm **Chair's Reflection and Preview of Day 2**
Sundaresan Jayaraman, Workshop Chair

4:30 pm **ADJOURN DAY 1**

DAY 2 – TUESDAY, MARCH 5, 2024

Welcome and Recap of Day 1

10:30 am **Chair Welcome and Opening Remarks**
Sundaresan Jayaraman, Workshop Chair

Session 5 Safety & Quality Considerations

10:45 am **Introduction**
Nicole (Nikki) McCullough, Vice President of Application Engineering and Regulatory, Personal Safety Division, 3M Company

In the last session in the series aimed at characterizing the impact associated with increasing the adoption of reusable versus disposable HCTs within health care settings, the panel will explore the impact of reusable HCT use on patient and health care worker safety using a risk-based assessment framework.

10:50 am **Case Study**
Ensuring That Reusable Respiratory Protective Devices Were Properly Cleaned/Disinfected During the COVID Pandemic
Hope Waltenbaugh, Vice President of Perioperative Services *&*
Sara Angelilli, Director, Education & Professional Practice, Allegheny Health Network

11:00 am **Panel Discussion**
Nicole (Nikki) McCullough, Panel Moderator

Functional Clothing and Textiles
- ***Wearability and Garment-Based Wearable Technology:*** *Lucy Dunne*, Professor, University of Minnesota

- ***Performance Comparison and Physiological Stress:*** *Meredith McQuerry*, Associate Professor, Florida State University

Health Care System Level
- *Mark Shirley*, Director, Integrated Resiliency Management, Sutter Health

Health Care Worker Level
- *Jill Morgan,* Critical Care Nurse, Emory University Hospital

Regulatory Perspective
- *Louise King,* Assistant Professor, Harvard Medical School

11:45 am **Audience Q&A**

Session 6 Decision-Making Support

11:55 am **Introduction**
Jacqueline Daley, Senior Director, Infection Prevention, Providence St. Joseph Health

In this session, the panel will consider the elements of a decision-support framework that a health care organization might consider when exploring the incorporation of more reusable HCTs into its operations.

12:00 pm **Case Study**
Decision Process to Incorporate More Reusable Isolation Gowns in Health Care Operations
Beth Schenk, Executive Director Environmental Stewardship & *Jack Holmberg*, Senior Infection Preventionist, Providence Health

12:10 pm **Panel Discussion**
Jacqueline Daley, Panel Moderator

Health Care Systems' & Organizations' Perspectives

- ***Large-Scale:***
  Skip Skivington, Vice President of Health Care Continuity and Support Services, Kaiser Permanente

- ***Small-Scale:***
  Barbara DeBaun, Improvement Advisor, Cynosure Health

User Perspective

- *Katherine Townsend,* Professor, Nottingham Trent University

12:55 pm **Audience Q&A**

1:05 pm **BREAK**

Session 7 Implementation

1:40 pm **Introduction**
Sundaresan Jayaraman, Workshop Chair

This final panel will close the workshop by discussing what it would take for a health care organization to implement use of more reusable HCTs. In addition to highlighting the implementation strategies and systems and behavior change models that each panelist relied on to promote the increased use of reusable HCTs in their health care setting, the panel will also address barriers to adoption that were encountered.

1:45 pm **Panel Discussion**
Sundaresan Jayaraman, Panel Moderator

Health Care System with Both On- and Off-Site Laundry Services

- *Laura Thurston,* Director, Laundry Services, Intermountain Health

Sustainability in Clinical Care

- *Cassandra L. Thiel,* Assistant Professor, NYU Grossman School of Medicine
- *Edward McCauley,* President & CEO, United Hospital Services

Health Care Worker Level

- *Jill Morgan,* Critical Care Nurse, Emory University Hospital

Intersection of Regulations and Health Care Worker Safety

- *Louise King,* Assistant Professor, Harvard Medical School

2:30pm **Audience Q&A**

Day 2 Wrap-Up

2:40 pm **Sponsor's Reflections**
Maryann D'Alessandro, Director, NPPTL

2:50 pm **Closing Remarks**
Sundaresan Jayaraman, Workshop Chair

3:00 pm ADJOURN

Appendix D

Biographical Sketches of the Workshop Planning Committee Members, Speakers, and Staff

PLANNING COMMITTEE BIOSKETCHES

Sundaresan Jayaraman, Ph.D. (*Chair*), is a professor in the School of Materials Science and Engineering at the Georgia Institute of Technology. He is also the founding director of the Kolon Center for Lifestyle Innovation at Georgia Tech. A pioneer in bringing about convergence between textiles and computing, Jayaraman's research has led to the paradigm of "Fabric is the Computer." He is a leader in studying and defining the roles of engineering design, manufacturing, and materials technologies in public policy for the nation. Jayaraman and his research students have made significant contributions in the following areas: (i) smart textile-based wearable systems; (ii) computer-aided manufacturing, automation and enterprise architecture modeling; (iii) engineering design and analysis of intelligent textile structures and processes; (iv) design and development of knowledge based systems (KBS) for textiles and apparel; and (v) design and development of respiratory protection systems. Jayaraman is a recipient of the 1989 Presidential Young Investigator Award from the National Science Foundation (NSF) for his research in the area of computer-aided manufacturing and enterprise architecture. In September 1994, he was elected a fellow of the Textile Institute, UK. His publications include a textbook on computer-aided problem solving published by McGraw-Hill in 1991 and 11 U.S. patents. As principal investigator, he has received over $16 million in research funding from a variety of sources including NSF, the Defense Advanced Research Projects Agency, the Department of Defense, the National Institute of Standards

and Technology, the Centers for Disease Control and Prevention, and industry. Jayaraman served as technical editor, information technology, for *ATI Magazine* (now *Textile World*) from 1995 to 2003. From May 2000 to October 2004, he was an editor of the *Journal of the Textile Institute* and is currently on the Editorial Advisory Board. Jayaraman is a founding member of the National Academies Standing Committee on Personal Protective Equipment for Workplace Safety and Health (2005–2013) and is currently serving on it. From December 2008 to February 2011, he served on the Board on Manufacturing and Engineering Design of the National Academies. In February 2011, he became a founding member of the National Materials and Manufacturing Board of the National Academies. He has also served on nine National Academies study committees. He is also a founding member of the IEEE Technical Committee on Biomedical Wearable Systems (2004–2008). In October 2000, Jayaraman received the Georgia Technology Research Leader Award from the State of Georgia. He received the 2018 Textile Institute Research Publication Award for the most outstanding paper published in 2018 in the *Journal of the Textile Institute*. In December 2019, he received the Inaugural Distinguished Alumni Award from A.C. College of Technology, Chennai, India. In 2020, he once again received the 2020 Textile Institute Research Publication Award. In 2023, he received the National Academy of Medicine Catalyst Award in the Global Healthy Longevity Challenge (https://bit.ly/47P5d3Y).

Elizabeth L. Beam, Ph.D., is an associate professor at the University of Nebraska Medical Center College of Nursing. She has worked on an emergency preparedness grant called HEROES at the college of nursing since 2005. In that role, she became a member of the Nebraska biocontainment unit leadership team and was the director for education in 2014 when Ebola virus disease was treated in the United States. She worked with that team to create and publish the personal protective equipment (PPE) ensemble used by the care team at Nebraska Medicine for this Category A illness. In 2018, the team won the American Industrial Hygiene Association's Edward J. Baier Technical Achievement Award, which is a lifetime achievement award in the field of industrial hygiene. Beam has gone on to do further research on health care worker behaviors in PPE for transmission-based precautions with an emphasis on respiratory protection for situations such as the COVID-19 pandemic. Her infection control behavior studies specifically used reusable isolation gowns as they were the product used by Nebraska Medicine at the time. She currently serves on the National Emerging Special Pathogen Training and Education Center PPE working group.

Gajanan S. Bhat, Ph.D., earned his doctorate from Georgia Institute of Technology in textile and polymer engineering and worked for indus-

try making carpets from recycled plastic bottles. Bhat joined the University of Tennessee, Knoxville in August 1990, where his research covered nonwovens—melt blown, spunbonded, and biodegradable; plastics recycling; nanotechnology; sustainable materials; and high-performance fibers. As the director of University of Tennessee Nonwovens Research Laboratory, he demonstrated successful production of nanofibers from thermoplastic polymers by melt blowing. In July 2016, he joined the University of Georgia as the head of the Department of Textiles, Merchandising, and Interiors. He has served as president of the Fiber Society and is also an active member of the Association of the Nonwoven Fabrics Industry and the Technical Association of the Pulp & Paper Industry (TAPPI). Some of the awards/recognitions he has received include Outstanding Young Engineering Alumni by Georgia Tech; Distinguished Achievement Award from the Fiber Society; Fellow of the Textile Institute; and TAPPI Nonwovens, Engineers and Technologists division Technical Achievement Award. He has published more than 250 research papers and made over 300 presentations.

JACQUELINE A. DALEY, H.B.SC, MLT, CIC, CSPDS, FAPIC, is the senior director, infection prevention at Providence St. Joseph Health in Irvine, California and an infection prevention consultant, a certified infection preventionist and an Association for Professionals in Infection Control and Epidemiology (APIC) Fellow with over 35 years of experience working in hospitals and ambulatory care settings. Daley is a member of the Association for the Advancement of Medical Instrumentation, sitting on a number of working groups including Protective Barriers. She is a member of the ASTM Personal Protective Clothing and Equipment Committee and was the former sub-vice chair for the Biological Hazards Subcommittee. She was a former member of the California Department of Public Health, Healthcare-Associated Infections Advisory Committee. She presents at local, national, and international conferences and meetings on various infection prevention topics including reprocessing of endoscopes, sterilization, and disinfection, and prevention of surgical site infections. She has a number of collaborative published articles on prevention of surgical site infections and has authored a chapter on "Central Service Leaders and Infection Prevention" in the *Central Service Leadership Manual* published by the International Association of Healthcare Central Services Materiel Management. Daley is a member of APIC, AORN, the Society for Healthcare Epidemiology of America, the Society of Gastroenterology Nurses and Associates, Inc., and the Healthcare Sterile Processing Association. She was also named one of the 50 experts leading the field of patient safety by Becker's *Hospital Review* in 2015.

Melissa Dawson, M.S., is an associate professor and program director of industrial design at Rochester Institute of Technology in Rochester, NY. Before transitioning back to academia, Dawson spent 8 years in the textiles and apparel industry as a textile and soft-product designer. Working for a manufacturer, vendor, and retailer allowed her to learn and experience the textile and soft-product design industry from all sides. She has spent both her professional design and academic careers espousing the technological complexities of successful soft-product design. Her primary research focuses center on the reclamation and reuse of post-consumer textile waste into new nonwoven composite materials, as well as the Clear Mask Project which emphasizes creating accessible and equitable personal protective equipment for underserved populations. Dawson is on the Fulbright Specialist roster and is an active member of the Technical Association of the Pulp & Paper Industry; New York State Association for Reduction, Reuse and Recycling Textile Council; and W4R: Women for Reduction, Reuse, Recycling, and Rethinking Strategies for Managing Materials. She received her B.S. in textiles and apparel from Cornell University and her M.S. in textile design from Philadelphia University. She is currently pursuing her Ph.D. in textile engineering and sciences at Thomas Jefferson University.

Elizabeth P. Easter, Ph.D., received her M.S. and Ph.D. in textile science from the University of Tennessee, Knoxville. She teaches Textiles for Consumers and Research Methods. Her research in textile science is applied research focusing on protective clothing, laundry fundamentals, and quality evaluations of textile and apparel products. In 1988, Easter established the Textile Testing Laboratory. The laboratory has provided contractual fee-based services to more than 50 corporations and organizations for testing textiles during product development, performance, and durability evaluations. A grant contract with the Association for Linen Management, the professional organization of facility and laundry managers of health care and hospitality laundries, has generated $1,019,855.00 over the past 36 years.

Nicole (Nikki) V. McCullough, Ph.D., CIH, is vice president of Application Engineering and Regulatory in the Personal Safety Division of 3M Company based in St. Paul, MN. She has been with 3M's Personal Safety Division for more than 26 years, working in product development, technical outreach, and regulatory affairs. In her role she has engaged with the occupational health and safety communities regarding the use of personal protective equipment in Latin America, Europe, and Asia as well as the United States and Canada. McCullough is a certified industrial hygienist and has a Ph.D. from the University of Minnesota in environmental health

with a focus in industrial hygiene where she studied control of airborne infectious diseases using respiratory protection. She has engaged in many forums regarding infectious-outbreak and pandemic-planning response, published numerous articles, and participated in many conferences focused on improving worker health and safety as well as contributed to standards development activities.

Barbara Strain, M.A., is an independent health care value consultant. She is retired from University of Virgina (UVA) Health, where she held various positions including manager of clinical microbiology, director of value management, director of supply chain operations, director of linen operations, director of surgical supply, and member of the sustainability and safety and security committees. Strain's expertise spans microbiology, virology, disinfection, sterilization, textiles selection and contracting, sustainability assessments, supply chain, and value analysis. She is also a member of the Association of Healthcare Value Analysis Professionals (AHVAP), Healthcare Surfaces Institute (board member), American College of Healthcare Executives, Association of Healthcare Resource & Material Managers, and Bellwether League Foundation (chair). She has been honored with numerous awards including the Brooke Berson Founder's Award—AHVAP and the Hall of Fame Class of 2021—Bellwether League Foundation.

Kelly N. Wright, M.D., is the director of the Division of Minimally Invasive Gynecologic Surgery and an associate professor of obstetrics and gynecology at Cedars-Sinai Medical Center in Los Angeles. She currently serves Cedars-Sinai in several capacities by promoting cost-effectiveness and sustainability in health care, implementing enhanced recovery after surgery, increasing telehealth utilization, and decreasing hospital waste production. She serves on Cedars-Sinai's executive sustainability committee and has consulted with medical device companies on reusable equipment and sustainability initiatives. She has given more than 25 keynote talks and grand rounds on health care's impact on climate change, pollution, and waste. She lives the reality of medical waste and operating room supply chain processes as a high-volume surgeon. She currently is a Fellow of the American Congress of Obstetricians and Gynecologists and of the American College of Surgeons. She serves as a board member of AAGL and is a member of the Society of Gynecologic Surgeons. She received a B.S. in biomedical engineering and an M.D. from Texas A&M University, graduating from both programs with honors. She did her residency at the Brigham and Women's and Massachusetts General Hospital combined program in obstetrics and gynecology and her fellowship in minimally invasive gynecologic surgery at Newton-Wellesley Hospital in Massachusetts.

SPEAKER AND PANELIST BIOSKETCHES

Laurie-Ann Agama, M.S., Ph.D., is the Acting Assistant U.S. Trade Representative for Textiles, responsible for advising the U.S. Trade Representative (USTR) on textile and apparel trade policy matters, conducting negotiations affecting textile and apparel products, and working to expand the industry's access to foreign markets. Dr. Agama has served as the Deputy Assistant U.S. Trade Representative for Economic Affairs in the Office of Trade Policy and Economics since 2012, where she has led USTR's strategic planning processes and provided economic analysis and advice for U.S. trade policy development and implementation, trade negotiations, dispute settlement cases and to resolve trade policy and investment-related issues. She joined USTR in 2004 as director in the Office of African Affairs, where she supported the development of initiatives to enhance U.S. trade and investment relations with the countries in sub-Saharan Africa, including the implementation of the African Growth and Opportunity Act. Agama holds master's and doctoral degrees in economics from McGill University and is an International Career Advancement Program Fellow.

Sara Angelilli, D.N.P., M.S., RN, CNOR, NPD-BC, is the director of nursing education and professional practice for perioperative, procedural, and para-professional education at Allegheny Health Network. She has 16 years of nursing experience with 7 years in education and professional development. Angelilli graduated with her doctorate in nursing practice with a concentration in nursing administration from Capella University. Sara received dual master's degrees in industrial and organizational psychology and nursing education and leadership. She is dual-certified in perioperative nursing and in nursing professional development. She participated as a co-investigator on the federally funded grant to explore preferred uses and best practices for elastomeric half mask respirators in the health care setting and is co-author on several related papers.

Gio Baracco, M.D., is an adult infectious disease specialist and hospital epidemiologist in Miami, Florida. He is a professor of clinical medicine in the Division of Infectious Diseases at the University of Miami Miller School of Medicine. He is the associate chief of staff for Hospital Epidemiology and Occupational Health at the Miami Veterans Affairs (VA) Healthcare System and serves as senior advisor for emerging infections to the VA Under Secretary for Health in Washington, D.C. Baracco has a long-standing interest in health care epidemiology and health care preparedness and response to high-consequence infections. He has authored multiple papers on emergency stockpiles, including tools to understand

cost implications of reusable personal protective equipment and stockpiling priorities.

Barbara DeBaun, M.S.N., RN, CIC, has over 40 years of experience in the fields of infection prevention, patient safety and quality improvement. She provides coaching and team facilitation to health care facilities of all sizes from large academic medical centers to critical access hospitals. DeBaun earned her Bachelor of Science in Nursing degree from Pace University in New York and her Master of Science Nursing degree from San Francisco State University. Her infection prevention career has been bookended by two pandemics. She was a pioneer in the early days of HIV/AIDS who championed health care worker safety and protection from blood-borne pathogen exposures. She has extensive experience navigating the challenges that the COVID-19 pandemic posed on personal protective equipment availability and efficacy.

Lucy E. Dunne, Ph.D., is a professor in the Department of Design, Housing, and Apparel in the College of Design at the University of Minnesota. She is also co-director of the Wearable Technology Lab. Dunne is a co-author (with Susan Watkins) of *Functional Apparel Design: From Sportswear to Space Suits* (Fairchild Books, 2015). Her research is focused on wearability and garment-based wearable technology, and explores new functionality in apparel, human–device interfaces, production and manufacture, and human factors of wearable products. Dunne has received the National Science Foundation's CAREER award and the NASA Silver Achievement Medal for her work with functional clothing and wearable technology.

Pamela Falk, M.P.H., CIC, FSHEA, FAPIC, has worked in the infection control field for more than 40 years, and is currently president of Pamela S Falk Consulting. She is a fellow of the Association for Professionals in Infection Control and Epidemiology (APIC) and the Society for Healthcare Epidemiology of America (SHEA). She has experience in university and community acute care and ambulatory health care settings. She holds a master of public health in infectious diseases epidemiology from the University of Michigan and is certified in infection control. She has authored many papers, and presented nationally at APIC, SHEA, and the American Medical Association (AMA). Falk was the APIC representative during the creation of the Centers for Disease Control and Prevention (CDC)/Johns Hopkins instructional video for donning and doffing for Ebola, edited the voice-over copy, and is seen in sections of the video. She edits sections of the The Joint Commission/Occupational Safety and Health Administration Course Review and Updates for Elsevier publishing. Falk is an APIC consultant and is the past education chair of the Atlanta APIC chapter.

She is the creator of The Don and Doff Fashion Show at the 2015 and 2016 National APIC Live show and created Battles of the IP (Jeopardy) game at the 2017 and 2018 National APIC Live show. She also created the section of the APIC skills lab "Outpatient Infection Prevention." Falk is a past member of the APIC National Education Committee. Most recently she has been working with acute care facilities, long-term-care facilities and ambulatory care sites on issues related to COVID-19. Her focus has been on hand hygiene, proper use of personal protection equipment (PPE), including extended use of PPE, and cleaning and disinfection of the environment. Falk currently lends her experience of COVID-19 to the national APIC COVID-19 task force. Falk has lent her epidemiology experience to many *Legionella* projects in several institutions including investigating *Legionella* outbreaks, creating a water management plan, and developing a water testing program. She attends the CDC Healthcare Infection Control Practices Advisory Committee (HICPAC) meeting on a regular basis to keep up with the most recent guidelines.

Shawn G. Gibbs, Ph.D., M.B.A., CIH, is dean of the Texas A&M University School of Public Health. Gibbs has over 100 articles in industrial hygiene focusing on disrupting transmission of high-consequence infectious diseases. He is a member of the Board of Directors of Global Environmental Health and Safety Credentialing and Clinical Laboratory Improvement Advisory Committee Biosafety Working Group. He was a member of the U.S. Environmental Protection Agency Board of Scientific Counselors for Homeland Security and the Southeastern Conference Medical Task Force. He was a U.S. Faculty Fulbright Scholar to Egypt and lead three Institutional Fulbright Faculty Scholars training programs for Public Health Curriculum Development. At the Nebraska Biocontainment Unit, he led and performed aeromedical evacuation, waste handling, and safety and risk reduction involved in the treatment of confirmed and under-investigation patients with Ebola virus disease in Nebraska and the United States. His research helped determine national policies, procedure, and best practices for response to Ebola virus disease, COVID-19, and other high-consequence infectious diseases.

Dan Glucksman is the public affairs director at the International Safety Equipment Association (ISEA). He is known as a strategic and goal-oriented association professional, who has taken ISEA's government relations programs to new levels. He provides ISEA member companies with actionable insights on federal policies, allowing these employers to grow revenue and minimize risk. He has led several congressional and regulatory visits for manufacturing executives to achieve strategic objectives. His event management and planning skills have led to successful annual

meetings and executive summits. In addition, his team-oriented approach has led to successful events. He has expanded stakeholder engagement through coalition participation and direct outreach. These activities have led to strategic alliances that move the association forward.

Jack Holmberg, RN, BSN, CIC, is an infection preventionist at Providence Willamette Falls Medical Center (PWFMC), practicing as a registered nurse in the Emergency Department for nearly 10 years before transitioning to Infection Prevention and Control. He holds a bachelor of science in environmental studies and a genuine interest in sustainability, environmental health, and infection prevention. Holmberg believes that there is much opportunity to improve sustainable practices in the health care field. Contrary to widespread belief, he thinks infection prevention can play a pivotal role in identifying new sustainable practices. He is co-chair of the Green Team at PWFMC and enjoys collaborating with a multidisciplinary team to solve complicated problems while looking for ways to keep patients safe and reducing Providence's carbon footprint. In his free time, he enjoys spending time with his family, being outdoors, and playing music.

Louise King, M.D., J.D., is an assistant professor of obstetrics, gynecology, and reproductive biology at Harvard Medical School and a surgeon within the Division of Minimally Invasive Gynecologic Surgery at Brigham and Women's Hospital. Dr. King completed her juris doctorate at Tulane Law School before attending medical school at the University of Texas Southwestern Medical Center. She completed her residency in obstetrics and gynecology at Parkland Hospital in Dallas, Texas, and her fellowship in minimally invasive surgery with Dr. Camran Nezhat at Stanford University. Her areas of interest in medical ethics focus on questions of informed decision making and assisted reproduction as well as equitable access to advanced gynecologic surgery.

Maryann D'Alessandro, Ph.D., has served as director of the National Institute for Occupational Safety and Health (NIOSH) National Personal Protective Technology Laboratory (NPPTL) since March 2012. She also served as the associate director for science for NPPTL from 2003 to 2012. D'Alessandro provides leadership to the NIOSH Personal Protective Technology (PPT) Core and Specialty Program and the Public Safety Program where she serves as the manager leading the effort to align PPT initiatives with user needs across all workplace industry sectors. Within the PPT program, D'Alessandro has served as the catalyst for aligning surveillance, research, standards, certification, outreach, and intervention activities to improve workplace safety and health. She has played a key role in the COVID-19 response including leading personal protective

equipment (PPE) research, respirator conformity assessment, combatting counterfeit and substandard PPE, and addressing respiratory protection needs for the general public.

James Marvel, M.D., is a clinical assistant professor of emergency medicine at Stanford University. His clinical focus is on emergency and wilderness medicine. Marvel is also a member of the Wu Tsai Human Performance Alliance. Marvel earned his M.D. from Columbia University College of Physicians and Surgeons and completed a fellowship at Stanford University Emergency Medicine.

Edward McCauley, M.B.A., has been in the laundry business for nearly 40 years. He started in 1983 with AraTex Uniform in Bethlehem, Pennsylvania, and then moved on to Hospital Central Services Cooperative Laundry in Allentown, Pennsylvania. At the Hospital Services Cooperative Laundry, he held several mid-level management positions and finally moved to United Hospital Services in Indianapolis where he has been for the past 22 years as the chief operating officer and chief executive officer. McCauley has spent time on several industry-related boards including the International Association of Healthcare Textile Managers, the American Reusable Textiles Association, the Healthcare Laundry Accreditation Council, in addition to the Make-A-Wish Foundation of Ohio, Kentucky, and Indiana. McCauley has a B.S. from Penn State University and an M.B.A. from Wilkes University.

Meredith McQuerry, Ph.D., is the Carol E. Avery Associate Professor of Textile Science in the Jim Moran College of Entrepreneurship at Florida State University. She directs the ThermaNOLE Comfort Lab® and Textile Testing Laboratory where her research focuses on engineering better-performing personal protective clothing and equipment for multiple end-user applications. Her work focuses primarily on reusable personal protective equipment for health care workers, first responders, soldiers, and athletes. She has received nearly $4 million in research funding including a $1.5M grant from Federal Emergency Management Agency to continue to explore the development of better-fitting female firefighting gear. Work led by Dr. McQuerry on disposable versus reusable medical gown performance has been recognized internationally as it identifies the advantages of reusable gowns in a primarily disposable market. In total, Dr. McQuerry's work has been published through more than 30 journal articles and more than 80 presentations.

Charlie Merrow is the chief executive officer and managing director at The Merrow Group Companies. Merrow is also on the Southcoast

President's Council at Southcoast Health, the Academic Center for Entrepreneurship Advisory Committee at Bristol Community College, and the Advisory Board of Charlton College of Business at University of Massachusetts Darthmouth. Merrow attended DePauw University and Cheltenham College.

JILL MORGAN, B.S., is a nurse with over 35 years of bedside experience in emergency and critical care medicine. She is on Emory's biocontainment team and cared for Emory's viral hemorrhagic fever patients. She now serves as the site manager for the Emory biocontainment unit and has worked to validate the unit's protocols, including the inactivation of Category A waste and the safe doffing of complex personal protective equipment (PPE) ensembles. She is a PPE subject-matter expert and co-lead of the PPE Working Group for National Emerging Special Pathogens Training & Education Center (NETEC), the National Emerging Special Pathogens Training and Education Center, an Administration for Strategic Preparedness and Response–funded organization charged with improving the readiness of the U.S. health care system for infectious pathogens. For NETEC, she helps create and deliver frontline education; evaluate ensembles, protocols, and plans; and assess the readiness of healthcare facilities. She is a member of ASTM, Association for the Advancement of Medical Instrumentation, and Association for Professionals in Infection Control and Epidemiology.

MICHAEL OVERCASH, PH.D., is the executive director of the Environmental Genome Initiative which has one of the largest chemical life-cycle databases. He has set the standards for the quality control and peer review of all the environmental genome elements to date (about 1,600 chemical plant analyses). He is on the board of directors and is helping to develop the various utilization communities that will develop analytics for the open-source environmental genome database. Overcash served as a professor in chemical engineering and in biological and agricultural engineering at North Carolina State University. Recently he served as the Sam Bloomfield Chair in Sustainable Engineered Systems at Wichita State University. His life-cycle research has focused on health care, reusable textile technology, recycling of chemicals, and prevention of hospital-acquired infections. He received his Ph.D. from the University of Minnesota in chemical engineering.

SHELLEY PETROVSKIS is director of marketing and regulatory affairs for Lac-Mac Limited, a manufacturer of high-performance personal protective equipment (PPE) for health care and other industrial markets. With over 42 years' experience marketing and promoting the environmental

merits of reusable health care textile products, she has a deep understanding of the many benefits that reusables can deliver. She has a wide range of experience with the complexity of manufacturing reusable technical PPE, and the standards and regulatory requirements that govern medical devices. Petrovskis is an active member of the American Reusable Textile Association, Textile Rental Services Association, and American Linen Management and supports the International Association for Healthcare Textile Management. She has an understanding of the challenges presented and the rewards observed when converting from a disposable program. Her expertise on technical barrier products provides a solid foundation for supporting customers through their journey to more sustainable products.

Liz Remillong, B.S.B.A., is currently a vice president for Core Linen Services (formerly Crothall Laundry Services) with over 40 years commercial health care laundry management experience. Remillong has provided hospital linen rental services or linen processing services to health systems across the country, including Alaska and Hawaii. She has provided management services to numerous health care cooperative laundries as well as consulting services to health systems and laundries looking for improvements. Her vast and varied experience in the commercial health care laundry space enables her to be considered a subject-matter expert in this field. Additionally, Remillong is a board member for Textile Rental Services Association (TRSA), on the Advisory Board for TRSA's Hygienically Clean certification, a member of the Association for Linen Management, the American Reusable Textile Association, and numerous other health care–related organizations and associations.

Elizabeth Schenk, Ph.D., RN, FAAN, serves as chief environmental stewardship officer for Providence, one of the nation's largest nonprofit health systems. Schenk and team lead Providence's efforts through strategy and innovation, efficiency of practices and processes, and research, education, and engagement, built on her experience decreasing the environmental impacts of health care for more than 30 years. She is an assistant research professor at Washington State University College of Nursing. She led the development of the Climate, Health, and Nursing Tool (CHANT), measuring health professionals' awareness of and engagement in climate change and health. CHANT has been translated to several languages and used in over 40 nations. She developed the WE ACT Framework (Waste, Energy/water, Agriculture/food, Chemicals, Transportation) to organize the extensive range of environmental stewardship, while motivating action. She is active at national, state, and local levels, serving on the Expert Panel on Environmental and Public Health for the American

Academy of Nursing. She is treasurer for the state organization Montana Health Professionals for a Healthy Climate, and board chair for the local organization Climate Smart Missoula. She hosts the Nurses for Healthy Environments Podcast, now in its sixth season.

Lynne Sehulster, Ph.D., was previously part of the Division of Healthcare Quality Promotion National Center for Infectious Diseases at the Centers for Disease Control and Prevention.

Mark Shirley, M.S., is director of Integrated Resiliency Management in the Office of the General Counsel at Sutter Health. He provides corporate-level leadership and guidance across a broad range of environmental health, safety, and emergency management operations in support of risk mitigation, regulatory compliance, and organizational resiliency. Shirley received his master's degree in environmental management from the University of San Francisco in 2000 and has been a board-certified safety professional since 2006. He currently serves as a member of the California Department of Public Health's Joint Advisory Committee on Public Health Preparedness, the California Hospital Association's Emergency Management Advisory Committee, and the Hospital Incident Command System National Advisory Executive Committee.

Erika Simmons, M.B.A., is the technical director at the American Association of Textile Chemists and Colorists (AATCC) where she is accountable for AATCC standards development, research committees, and testing materials support. Prior to AATCC, she worked for a branded apparel company where she held various roles in product development, International Standards Organization (ISO) 17025 lab accreditation management, and customer compliance. She received her M.B.A. from Wake Forest University and an undergraduate degree in textile engineering from North Carolina State University.

Skip Skivington, M.B.A., is vice president, Health Care Continuity and Support Services at Kaiser Permanente. Skivington concurrently served as the interim vice president of supply chain during the period of 2005 to 2009, and from 2015 to 2017 led Kaiser's security services program. Since 2000, he has been responsible for the implementation of a formal healthcare continuity management program throughout Kaiser Permanente. In addition to directing this formal planning and response process, and immediately following the anthrax attacks in October 2001, he formed and now directs Kaiser Permanente's threat assessment program consisting of an executive oversight council, and functional working groups in the disciplines of clinical (physicians, nursing, pharmacy, mental health and

lab), facilities, community linkages, people, legal, communications, training, supply chain, and public policy. He serves as Kaiser Permanente's national incident manager during wide-scale events such as the Ebola crisis from 2014 to 2015 and the California wildfires in 2017. Following Hurricanes Katrina and Rita, Skivington led two Kaiser Permanente volunteer medical response teams consisting of physicians, nurses, and mental health providers to the Gulf Region at the specific request of the U.S. Surgeon General and was part of the largest medical volunteer response program in the history of the country. Skivington holds both a bachelor of science degree in business administration, and an M.B.A.

ADAM SMITH, M.S., PH.D., is currently a senior scientist at the National Personal Protective Technology Laboratory (NPPTL) at the Centers for Disease Control and Prevention. At his current position, he provides senior-level, strategic and operational planning, scientific guidance, and engineering consultation to a national conformity assessment infrastructure (CA Infrastructure). He also manages (1) the strategic development and implementation of NPPTL research, standards development, and postmarket activities with an emphasis on respiratory protection, sensors, and emerging technologies assuring that worker protection needs are met; and (2) the design and implementation of projects or strategic planning initiatives to meet short-term and long-term executive goals. Smith leads the development and execution of research and learning agendas to address high-priority worker safety and health issues associated with personal protective equipment, especially where policy and science intersect. Prior to his current position, Smith was deputy director of the Pittsburgh Mining Research Division at NPPTL where he directed and coordinated the full range of supervisory and management duties over subordinate supervisors across the mining program. Smith earned his master of science in mechanical engineering from the University of Pittsburgh and his doctor of philosophy in mechanical engineering from Michigan Technological University.

JEFFREY O. STULL, M.Ch.E., is president of International Personnel Protection, Inc., which provides research, testing, and consulting services across a range of personal protective equipment (PPE) in multiple industries, including health care. He has specifically been involved in the development of multiple standards for PPE in the medical area including protective apparel, medical masks, barrier face coverings within several standards organizations such as ASTM International, the National Fire Protection Association, and the International Standards Organization. His organization has been engaged in multiple efforts to develop various forms of medical PPE, including reusable garments, for U.S. government

programs as part of contractual research programs. Stull has also provided expertise in the area of product compliance and regulatory oversight for different forms of health care PPE that have included clearance of medical devices and third-party certification of emergency responder PPE. His work has support from government, academic, labor union, end-user, and manufacturing interests.

Cassandra L. Thiel, Ph.D., is an assistant professor at New York University in the Grossman School of Medicine's Departments of Population Health and Ophthalmology and the Tandon School of Engineering's Department of Civil and Urban Engineering. She is also president and CEO of Clinically Sustainable Consulting LLC. Her research utilizes life-cycle assessment and principles of industrial ecology to analyze and improve the environmental performance of medical systems, hospital design, health care practice, and medical technologies. As a 2014–2015 Fulbright-Nehru Academic and Professional Excellence fellow, Thiel calculated the environmental footprint of cataract surgery at Aravind Eye Care System in southern India, finding that Aravind's carbon footprint for phacoemulsification was 5 percent of the same surgery done in the United Kingdom. She received her Ph.D. from the University of Pittsburgh and B.S. from Michigan Technological University, both in Civil Engineering.

Laura Thurston, M.S.B.M., C.L.L.M., is the laundry operations manager at Intermountain Healthcare. Her professional experience includes 35 years working in the support service lines in health care. She has a background in environmental services, transport services, valet services, and linen distribution services in Utah hospitals. Her leadership experience includes 26 years in environmental services management, 4 years as laundry production manager, and 3 years as laundry operations manager for Intermountain Health North Salt Lake Laundry, which produces 18.5 million pounds of clean linen annually. Her current position includes 2 years as director of linen services for Intermountain Health. Her professional associations include Association for Linen Management and International Association for Healthcare Textile Management. She has a M.S.B.M. and a CLLM certification and is currently working on an M.B.A. with a focus on global supply chain management.

Katherine Townsend, Ph.D., is professor of fashion and textile practice, aligned to the Fashion and Textile Research Centre, Nottingham Trent University, UK. Following a career as a fashion designer, her research and supervision is dedicated to the development of participatory methodologies, toward emotional durability and social and sustainable design. Townsend has collaborated with different groups of "overlooked wearers," including older women (Emotional Fit, 2017–2020) home-

less and vulnerable people (NTU X Emmanuel House, 2020–2023). Her Arts and Humanities Research Council–funded project, Redesigning PPE: Enhancing the Comfort and Safety of Healthcare Workers Wearing Isolation Gowns to Treat Patients with COVID-19 (2021–2023), resulted in a Circular Gown System informed by user and environment-centered approaches. Related research is focused on developing PPE repurposing solutions, and menopause-aware workwear to mitigate the discomfort—particularly heat stress—experienced by women working in the health care sector. Townsend is lead editor of *Crafting Anatomies* (Bloomsbury, 2020) and the journal *Craft Research*.

Henk Vanhoutte is the Secretary General of the European Safety Federation with over 30 years of experience in the personal protective equipment (PPE) sector. He represents the European PPE sector with the EU authorities and other stakeholders (such as notified bodies and standardization).

Tiffany Wiksten, D.N.P., RN, CIC, is currently an associate director in the Standards Interpretation Group in the Division of Accreditation and Certification Operations (ACO) at The Joint Commission and is an infection control subject-matter expert. In this role, Wiksten is responsible for working closely with accredited and certified organizations to interpret The Joint Commission standards, identify vulnerabilities, and improve their performance. She also responds to inquiries from accredited organizations and the public related to compliance with The Joint Commission standards. Wiksten reviews post-survey reports, clarifications, measures of success, and evidence of standards compliance submitted as part of the survey process. She provides leadership and guidance within the team in all aspects of the accreditation process through clinical expertise in infection prevention and control. She also supports customer relationship management and the field representative cadre as well as other customers through the provision of expert interpretation, guidance, and collaboration. Wiksten has worked as an infection preventionist for over 10 years. Prior to joining The Joint Commission, she was the manager of infection prevention at a major metropolitan medical center. She has led infection prevention programs and efforts in a variety of health care settings, including large academic medical centers, community hospitals, and ambulatory settings. Wiksten received a bachelor of science in nursing from Lewis University, Romeoville, Illinois, and a master of science in nursing from Loyola University, Chicago, Illinois, with a focus in population-based infection control and environmental safety. She received a doctor of nursing practice from Rush University, Chicago, Illinois, with a focus in transformational leadership. She holds a green belt in Lean Six Sigma and is certified in infection control.

JOHN WINTZ, M.B.A., is a group vice president for Standard Textile Co., Inc., working primarily in the Southeast and Mid-Atlantic areas of the United States. He is active with various industry and health care organizations including the Association for Linen Management, the American Reusable Textile Association, the Textile Rental Services Association, the International Association for Healthcare Textile Management, the Healthcare Infection Control Practices Advisory Committee, Vizient, and Premier. He began his career with Standard Textile Co., Inc. as a salesperson in the Dallas/Ft. Worth area over 37 years ago and first came to the Cincinnati corporate office as director of sales for the Repak Surgical Division as well as regional sales director for the Midwest region. The Repak division of Standard Textile offered reusable surgical gowns, towels, table covers, and drapes in a sterile format to health care systems in five areas in the United States. In his role at Repak, he had operating room nurses and salespeople reporting to him. He became a vice president and officer with Standard Textile Company in 2003. He has worked nationally in the Senior Living space, the laundry marketplace, the government sales area, the surgical product and services team and has managed Standard Textile's Consultative Services group. He has an undergraduate degree in marketing from Xavier University in Cincinnati and an M.B.A. in administrative management from University of North Texas in Denton.

PROJECT STAFF BIOSKETCHES

AUTUMN DOWNEY, PH.D., is a senior program officer with the Board on Health Sciences Policy. She joined the National Academies of Sciences, Engineering, and Medicine in 2012 and, in addition to the current study, she directs the Standing Committee on Personal Protective Equipment for Workplace Safety and Health. She was formerly the director of the Standing Committee on Medical and Epidemiological Aspects of Air Pollution on U.S. Government Employees and Their Families. Other National Academies studies she has worked on include Meeting the Challenge of Caring for Persons Living with Dementia and Their Care Partners and Caregivers; Evidence-Based Practice for Public Health Emergency Preparedness and Response; Return of Individual-Specific Research Results Generated in Research Laboratories; Preventing Cognitive Decline and Dementia; A National Trauma Care System; Healthy, Resilient, and Sustainable Communities After Disasters; BioWatch PCR Assays; and Advancing Workforce Health at the Department of Homeland Security. Downey received her Ph.D. in molecular microbiology and immunology from the Johns Hopkins Bloomberg School of Public Health, where she also completed a postdoctoral fellowship at the school's National Center

for the Study of Preparedness and Catastrophic Event Response. Prior to joining the National Academies, she was a National Research Council postdoctoral fellow at the National Institute of Standards and Technology, where she worked on environmental sampling for biothreat agents and the indoor microbiome.

Kelsey R. Babik, M.P.H., CIH, is an associate program officer in the Health and Medicine Division at the National Academies of Sciences, Engineering, and Medicine. In addition to this workshop, she works on projects initiated by the Committee on Personal Protective Equipment for Workplace Safety and Health. This is a standing committee at the National Academies sponsored by the National Personal Protective Technology Laboratory of the National Institute for Occupational Safety and Health, to provide a forum for discussion of scientific and technical issues relevant to the development, certification, deployment, and use of personal protective equipment, standards, and related systems to ensure workplace safety and health. Previously, at the Risk Sciences and Public Policy Institute of the Johns Hopkins Bloomberg School of Public Health, she worked on occupational health risk assessments for first responders. She is a certified industrial hygienist. She has a B.S. in molecular biology from the University of Pittsburgh, an M.P.H. from the University of Maryland, and is currently pursuing a Doctor of Public Health (Dr.P.H.) at the University of Illinois Chicago.

Emily McDowell, M.P.H., is a research associate with the Board on Health Sciences Policy of the National Academies of Sciences, Engineering, and Medicine. Most recently, she assisted with a consensus study, *Advancing Clinical Research in Pregnant and Lactating Populations Overcoming Real and Perceived Liability Risks*, and has contributed to other projects at the National Academies relating to health equity and policy. She is a M.P.H. graduate from George Washington University concentrating her studies on epidemiology and environmental health. Before joining the National Academies, McDowell worked for a nonprofit emergency management organization, Healthcare Ready, and assisted with the reauthorization of the Pandemic and All-Hazards Advancing Innovation Act (PAHPAIA). her studies at George Washington University concluded with the presentation of her thesis entitled "Microplastics and Human Health: An Inescapable Exposure." McDowell received her B.S. in community health, concentrating in global health at George Mason University.

Ashley Bologna, M.S., is a senior program assistant in the Health and Medicine Division at the National Academies of Sciences, Engineering, and Medicine. In addition to this workshop, she works on projects initi-

ated by the Committee on Personal Protective Equipment for Workplace Safety and Health. This is a standing committee at the National Academies sponsored by the National Personal Protective Technology Laboratory of the National Institute for Occupational Safety and Health, to provide a forum for discussion of scientific and technical issues relevant to the development, certification, deployment, and use of personal protective equipment, standards, and related systems to ensure workplace safety and health. She earned her master of science in global health at Georgetown University. She also has a B.A. in international relations and political science from Virginia Wesleyan University.

Laura Runnels, M.P.H., is the founder of LARC. Prior to founding LARC, Laura was a senior program analyst at the National Association of County and City Health Officials. Laura was born on a mountaintop in Tennessee, raised in a small town in Mississippi, and educated in Connecticut, California, and Missouri. She has over 15 years of experience working with local, state, and federal clients. As a convening specialist, she is known for designing and facilitating highly collaborative, efficient, and productive meetings. As a strategist, she guides individuals, organizations, and coalitions through technical and adaptive challenges. Laura earned her master's degree in public health, behavioral science, and health education from Saint Louis University and earned her bachelor of arts in American studies from Yale University.

Amy Schlotthauer, M.P.H., is the owner of AES Consulting Firm and collaborator with LARC. She has a master's degree in public health from the Rollins School of Public Health at Emory University and a bachelor's degree in anthropology from University of Wisconsin–Madison. Amy has over 18 years' experience in project management, grant writing, program evaluation, qualitative and quantitative research methods and data analysis, group facilitation and consensus building, and using these skills to help clients work collaboratively to answer a pressing public health question. Schlotthauer is a member of the American Evaluation Association, Safe States, Milwaukee Evaluation, and Wisconsin Public Health Association. She also serves on the Menomonee Falls Public Library Board and is a member of the Menomonee Falls Collective Impact project in her hometown of Menomonee Falls, Wisconsin.