White Paper:

The Application of Ultraviolet Light in Germicidal Wavelengths for Public Health

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Executive Summary

The current COVID-19 pandemic caused by the airborne transmission of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) virus has created an urgent need to evaluate the potential for applying various technologies for disinfection. This paper summarizes published findings on the application of ultraviolet (UV) light in germicidal wavelengths for disinfection of contaminated air and surfaces. Owners and managers of public facilities worldwide are considering UV light technology as a powerful tool for disinfecting indoor circulating air streams as well as high-touch surfaces. Understanding the key considerations of UV disinfection, such as wavelength, distance from source, and exposure time, is essential for selecting a system with the optimal features and specifications for safety and efficacy.

This paper resulted from the author's analysis of commercially available UV disinfection technologies. In this analysis, the Sterile-Bright® product line emerged as having the most promising UV disinfecting technology. Sterile-Bright® is a full-range UV/Ozone generator manufactured and sold by Ultra-Tech Lighting LLC in New Jersey (http://ultratechlighting.com/sterile_bright). It is capable of safely neutralizing viruses, bacteria, fungi, and spores through a proprietary, multi-tiered approach. Sterile-Bright® uses UV light at germicidal wavelengths to directly decompose pathogens through radiation. Unlike other UV lights, the Sterile-Bright® UV light is in the right frequency range to disrupt the oxygen molecule, generating ozone (O_3), which is a strong sterilizing agent. This combination of UV light and ozone provides an optimum solution for disinfection of contaminated air and surfaces. Sterile-Bright is further expanding their data portfolio and is in the process of designing a safety study with one of the foremost researchers and experts in indoor air quality. Results of this study will be the subject of a subsequent paper.

While COVID-19 is currently a global health emergency, Sterile-Bright® technology was developed and validated well before the outbreak of SARS-CoV-2 with a focus on livestock and poultry. The powerful combination of full-spectrum UV and ozone addresses Porcine Epidemic Diarrhea Virus (PEDv), African Swine Fever (ASF), Coronavirus, thrush, and other opportunistic infections. Accordingly, the Sterile-Bright® germicidal profile appears ideal for mitigating against domestic animal infections. There are applications of Sterile-Bright® technology in addition to addressing SARS-CoV-2 and domestic animal infections. Sterile-Bright® has the potential to be a versatile, adaptable and important public health solution for the foreseeable future.

Introduction

Pathogens, including the SARS-CoV-2 virus, are able to spread and be transmitted by air or surface routes.[1] As such, the Centers for Disease Control and Prevention (CDC) as well as other health agencies have put out guidelines to prevent infection spread, including social distancing, regular hand washing and wearing facial coverings. However, these recommendations are often not followed by everybody, and additional protective measures are urgently needed, particularly in indoor environments where contaminated circulating air or high-touch surfaces can mediate transmission. UV light and ozone can disinfect circulating air as well as surfaces that cannot be easily reached by conventional disinfecting sprays or wipes. In fact, a May, 2020 New York Times article describes multiple ways that scientists are considering using indoor ultraviolet light to neutralize coronavirus in the air.[2] Dr. Edward A. Nardell, a professor of global health and social medicine at Harvard Medical School, is quoted in the New York Times article as describing ultraviolet germicidal irradiation (UVGI) as "highly effective, very safe technology."[2] He further asserts, "We've done the studies. We know it works."[2]

UV Disinfection

As confirmed by Dr. Nardell, UV disinfection has been a proven and validated technology for the disinfection of pathogens in air as well as on surfaces for several decades.[2,3] Very simply, UV light is electromagnetic radiation with wavelengths shorter than visible light but longer than X-rays. UV is categorized into four major categories based on wavelength ranges: UV-A (400 – 315 nm), UV-B (315 – 280 nm), UV-C (280 – 200 nm), and vacuum UV (VUV, 100 – 200 nm).

UV-C is considered "germicidal UV" because wavelengths between about 200 nm and 280 nm are strongly absorbed by nucleic acids. The absorbed UV-C photons cause critical damage to the genomic system (nucleic acids and proteins) of microorganisms. Adenine−thymine bonds collapse, and pyrimidine dimers are generated between pairs of adenines. These pyrimidine dimers can prevent replication or can prevent the expression of necessary proteins, resulting in the death or inactivation of the microorganism.

Different UV-C sources with different performance characteristics have been utilized for disinfection. The most common UV-C light sources for disinfection include:

- Low vapor pressure mercury UV lamps, which emit UV light at 254 nm[4]
- UV light-emitting diode (UV-LEDs) lamps, which emit UV light at wavelengths between 255 and 280 nm[5]
- Far-UV-C radiating excimer and micro-plasma lamps, which emit UV light at 200−240 nm.[6]

In contrast, the Sterile-Bright® UV light emits UV light across most of the UV spectrum, from 180nm to 457nm.[7] This is one of several key advantages in disinfection that the Sterile-Bright® UV light product line boasts over these other UV sources. Sterile-Bright® UV light emits in the UV-A, UV-B, UV-C, and VUV ranges. In the VUV range of 180nm -

200nm, ozone is produced, which has its own germicidal activity, as highlighted in a later section of this paper.

UV disinfection is dependent on two important parameters: wavelength and total UV dose. Germicidal efficacy varies with UV wavelength, and the optimal wavelength is unique to each pathogen, although a number of pathogens are effectively inactivated by UV light in the 260 – 270nm range.[8] Published studies have also shown that krypton chloride excimer (KrCl*) lamps with peak emission of 222nm successfully inactivate viruses such as alpha and beta coronaviruses, influenza (H1N1), and adenovirus;[9-12] and bacteria such as Staphylococcus aureus, Escherichia coli, and Bacillus subtilis.[13,14] For any given wavelength, the degree of pathogen inactivation is based on the total UV dose. The UV dose (in mJ/cm^2) is derived by multiplying the delivered irradiance to microbial cells (in mW/cm^2) by the exposure time (in seconds).[15]

Dr. Anthony Griffiths, Associate Professor of Microbiology at Boston University School of Medicine and his team treated SARS-CoV-2 inoculated material with different doses of UV-C radiation and determined a dose of $5mJ/cm^2$ reduced SARS-CoV-2 virus by 99% in 6 seconds. Based on the data, it was determined that a dose of $22mJ/cm^2$ will result in a reduction of 99.9999% in 25 seconds.

Sterile-Bright® is a 300-watt or 400-watt source that generates a full range of UV light, including substantial energy in the ionizing range of <200 nm.[7] Because Sterile-Bright® emits UV light across most of the UV spectrum, it can target a very wide range of pathogens that are inactivated at different optimal UV wavelengths. In addition, Sterile-Bright® has significantly higher power output than conventional fluorescent UV bulbs, which typically range from only 10-watts to 40-watts and therefore require placement near the target to deliver effective UV doses. The efficacy of Sterile-Bright® is further enhanced by its 360-degree radial UV distribution.

Another differentiating feature of Sterile-Bright® bulbs is that they use magnetic induction lighting technology. As a result, Sterile-Bright® has a longer lifecycle and greater range than fluorescent, mercury vapor, or LED. Sterile-Bright® offers a much better value proposition than other UV disinfection platforms. For example, the Xenex® pulsed xenon robot is an expensive automated unit designed for static indoor environments and is relatively limited in applicability. Another approach that is less attractive than Sterile-Bright® from both the economic and the efficacy perspectives is using a 405nm UV-A light emitting diode (LED) that can continuously operate with people present. This low energy UV lacks intensity and is reliant on continuous exposure over extended periods of time to achieve UV doses capable of inactivating pathogens. UV-A LED can require up to sixteen hours of direct exposure to degrade E. coli or S. aureus and is less effective for heartier bacteria like C. diff and viruses like coronavirus.

Ozone and Other Ancillary Disinfectants Arising from UV Light

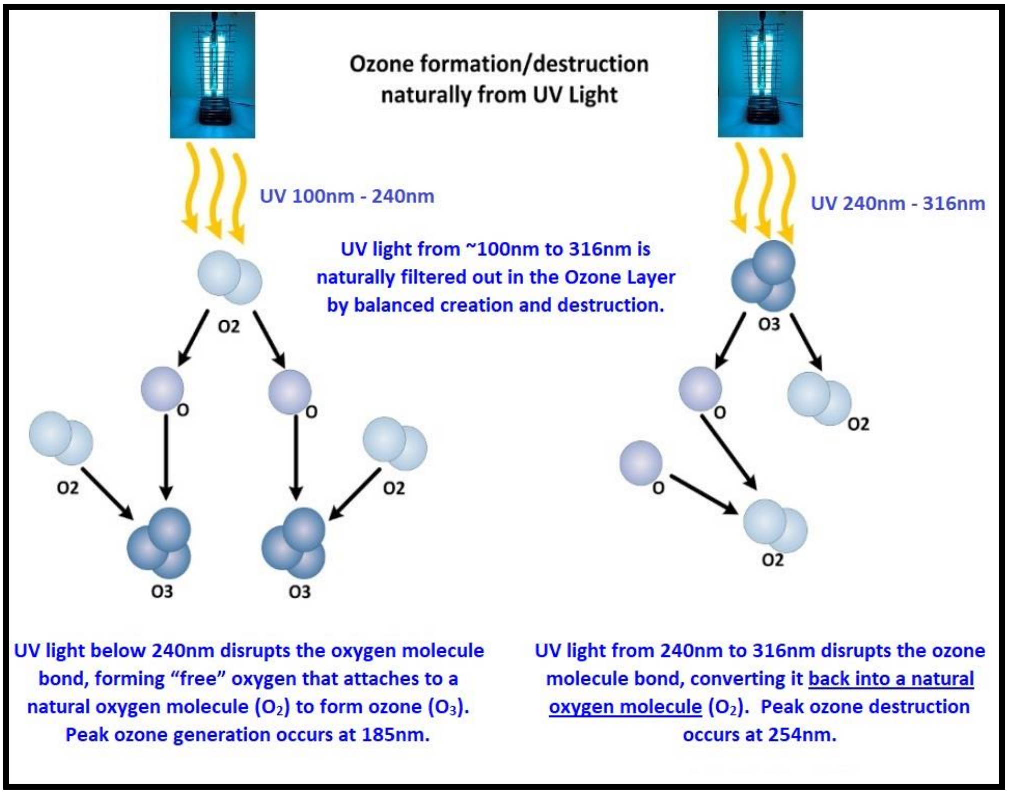
The combination of broad-spectrum UV light and the ozone it generates in the VUV range could be an incredibly effective approach for inactivating pathogens in air and on surfaces, easily reaching places that are less accessible to chemical disinfectants. Studies have shown that infectious droplet nuclei of diameter < 5 µm could remain suspended and transmitted by air current.[16] Recently, researchers in Japan studying the spread of coronavirus, found that microdroplets that can carry “many viruses” float in the air and drift. A single cough or sneeze can produce an estimated 100,000 microdroplets.[17] It is therefore of paramount importance to implement an effective system for disinfecting airborne pathogens in order to control disease spread.

Ozone (O_3) is an oxygen molecule containing three atoms. The more common oxygen molecule has two atoms (O_2); this is the oxygen we breathe. The extra atom of oxygen in ozone functions as a loose radical that seeks for organic molecules to attach to and thereby oxidize. Ozone reverts to the ubiquitous and harmless O_2 oxygen molecule after oxidation occurs, making ozone an eco-friendly oxidizer and disinfectant.

Ozone technology for disinfecting contaminated indoor typically uses gaseous ozone, which is colorless but has a characteristic odor. Ozone gas travels throughout indoor spaces and oxidizes organic molecules in the air as well as on surfaces. Ozone destroys microorganisms but does not reduce airflow.

Ozone is a powerful oxidizer. It can oxidize pathogens (thereby destroying them by rendering them unable to replicate), sterilize the air, and neutralize odors and toxic fumes. Like UV light, ozone has been used by industry for many years and in many different types of applications such as disinfection, water purification, and odor removal.[18]

VUV radiation generates ozone via photolysis of oxygen molecules in the air. Accordingly, ozone generation and UV irradiation can be combined in one UV system using the same lamp without the addition of any supplemental ozone dosage.[19] Ozone units or UV light units that generate ozone (such as Sterile-Bright®) can be placed in each room or installed in central units. Like UV disinfection technology, ozone disinfection technology comes with safe usage limits, and exposure levels can and must be controlled to meet government guidelines.



Source: Sterile-Bright® graphic

Sterile-Bright® units have many features that are ideal for inactivating pathogens that are airborne and/or on surfaces. As a byproduct of the emitted ionizing VUV energy, Sterile-Bright® units generate ozone that radiates several feet away from the unit. In addition to ozone, Sterile-Bright® units create other ancillary sterilization agents, including hydrogen peroxide (H_2O_2) from atmospheric water. The multiple sterilization pathways generated by Sterile-Bright® result in a comprehensive and effective non-chemical approach that addresses viruses, bacteria and other pathogens. Moreover, the Sterile-Bright® units cover greater areas and a wide range of pathogens because of the proprietary combination of ozone and hydrogen peroxide plus a full range of UV light with high-power output.

In addition, Sterile-Bright® technology balances ionizing VUV light with longer UV wavelengths that neutralize ozone by speeding conversion from O_3 back to O_2. This balance of ozone-destructive UV light and ozone producing VUV radiation ensures that dispersed ozone concentrations can be reasonably reduced within relatively short periods. This enables Sterile-Bright® to provide ozone disinfecting benefits while protecting against misuse. Sterile-Bright® units will never generate fumigation ozone concentrations > 25ppm. In general, both ozone and hydrogen peroxide have very short half-lives. Ozone and hydrogen peroxide vapor quickly dissipate under normal circumstances and do not pose health hazards after treatment.

Even so, Sterile-Bright® technology should only be used in evacuated spaces. Ideal uses include disinfecting the circulating air and surfaces in:

- Unoccupied indoor arenas prior to events
- Schools and classrooms outside of school hours
- Public transit systems during hours closed to the public
- The travel and hospitality industries (airlines, airports, hotels, cruise ships and other places) prior to guest arrivals.

Sterile-Bright® generators clean the air and may significantly reduce the risk of airborne transmission of viruses. Applying the UV light and ozone is generally quick and easy, because Sterile-Bright® units are portable and only require a minimal amount of time to treat the average room.

Sterile-Bright® Effectiveness Against SARS-CoV-2 Virus

Sterile-Bright® generators provide many technical and practical advantages for safe, quick, and cost-effective disinfection. Sterile-Bright® technology can be a powerful tool for managing public health during the COVID-19 pandemic, especially as the SARS-CoV-2 virus continues to mutate and new and more virulent variants emerge like the Delta.

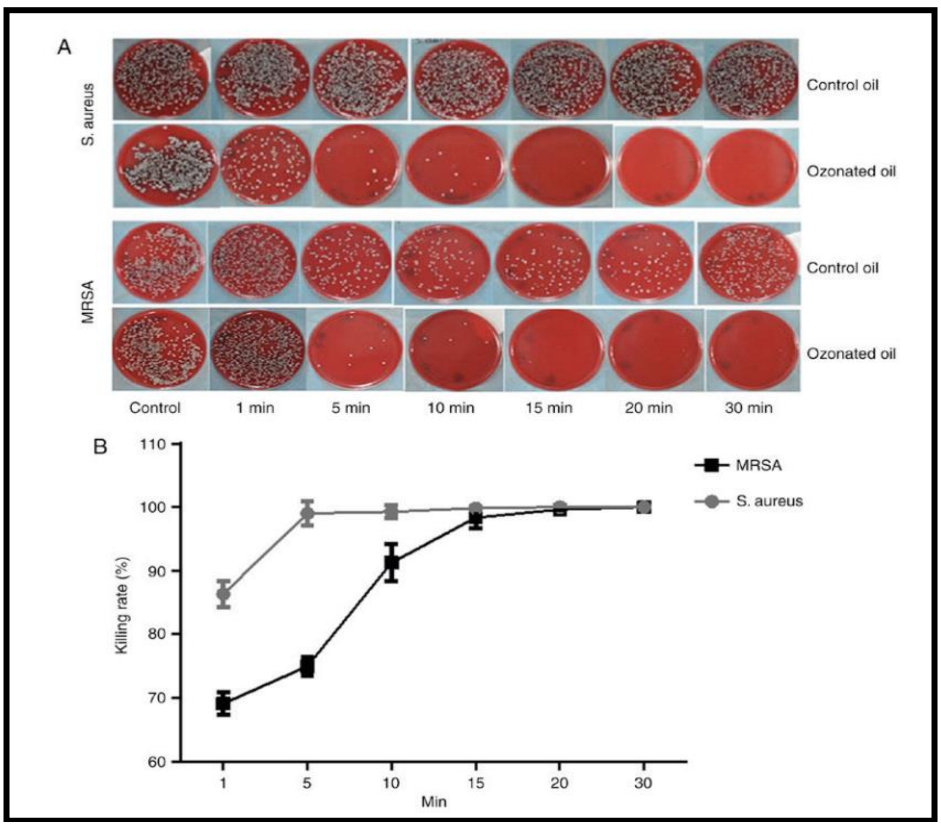
UV light and ozone (O_3) gas are effective against SARS-CoV-2, both airborne and on surfaces. In contrast, liquid agents, such as alcohol, hypochlorite (bleach), quaternary ammonium-based disinfectants, and detergents, typically only kill the SARS-CoV-2 virus on surfaces and not in the air.

A recent Fujita Hospital University study[20] demonstrated the effectiveness and safety of low-dose ozone gas and ozone water for SARS-CoV-2. Specifically, the study showed that ozone (O_3) at 0.1ppm to as low as 0.05ppm concentration deactivates SARS-CoV-2 at a 3 $\log_{10}$ reduction compared to control. Moreover, a separate study done recently by Biasin et. al.[21] on the effectiveness of UV_{254} against the SARS-CoV-2 virus demonstrated that UV_{254} light in as low a dose as 3.7mJ/cm^2 also deactivates SARS-CoV-2 at a 3 $\log_{10}$ reduction compared to control.

The data in these independent studies,[20,21] suggest that Sterile-Bright® can be the ideal method for SARS-CoV-2 disinfection in many situations and in many settings. Sterile-Bright®'s STRL-PU-250WUV unit emits 25mJ/cm^2 of UV_{254} light AND generates 3ppm of ozone (O_3) at 10 feet in less than 5 minutes. These are efficacious outputs of ozone and UV light for obliterating most viruses and bacteria, yet the ozone is Safe Germicidal Ozone (SGO) because Sterile-Bright® combines vacuum $UV_{180\text{-}200}$ with ozone-neutralizing $UV_{257\text{-}316}$ to balance ozone (O_3) production. This serves to maintain ozone concentration under 5ppm in a 20' x 20' x 9.5' space, significantly below any dangerous level for brief exposures. These performance characteristics make Sterile-Bright®'s technology suitable to safely kill variants of the SARS-CoV-2 virus in indoor places where there could be large gatherings during certain hours and no traffic at other times. These settings include sports arenas, schools, offices, restaurants, places of worship and certain areas of hospitals (diagnostic labs, etc.).

Sterile-Bright® Effectiveness Against Methicillin-Resistant *Staphylococcus aureus* (MRSA), Clostridium difficile (C. diff)

Beyond SARS-CoV-2 concerns, medical facilities have been plagued by opportunistic infections like staph and C. diff. In a paper entitled, "The Antibacterial Effect of Topical Ozone on the Treatment of MRSA Skin Infection," the authors demonstrate ozone efficacy in resolving methicillin resistant *Staphylococcus aureus* with an ozonated aqueous or oil application. Building upon the Fujita Hospital University findings, we see $\log^3$ reduction in MRSA within fifteen minutes. Killing rate of ozonated oil for *S. aureus* and MRSA. (A and B) at almost 100% *S. aureus* were killed in 5 min by ozonated oil. Almost 100% MRSA were killed within 15 min by ozonated oil. *S. aureus, Staphylococcus aureus*; MRSA, methicillin resistant *Staphylococcus aureus*. While the study pertains to specific in situ treatment of skin infection, ozone potency is evident in the results.



A Boston University compilation of effective UV-C_{254} ranges for destroying staphylococcus et. al. and e. coli at 90% (D90) in air and on surfaces reveals the following:

Microbe/Pathogen	D90/Media	Source

Staphylococcus albus	18 J/m^2 Surface	Sharp 1939
Staphylococcus albus	33 J/m^2 Surface	Rentschler 1941
Staphylococcus albus (1)	23 J/m^2 Air	Rentschler 1942
Staphylococcus albus (2)	52 J/m^2 Air	Rentschler 1942
Staphylococcus aureus	30 J/m^2 Surface	Sturm 1932
Staphylococcus aureus	50 J/m^2 Surface	Hollaender 1955
Staphylococcus aureus	66 J/m^2 Surface	Gates 1934
Staphylococcus aureus	26 J/m^2 Surface	Sharp 1939
Staphylococcus aureus	37 J/m^2 Surface	Luckiesh 1949
Staphylococcus aureus	19 J/m^2 Surface	Gates 1929
Staphylococcus aureus	20 J/m^2 Air	Nakamura 1987
Staphylococcus aureus	7 J/m^2 Air	Sharp 1940
Staphylococcus aureus	2 J/m^2 Air	Luckiesh 1949
Staphylococcus aureus	2 J/m^2 Air	Luckiesh 1946
Staphylococcus epidermis	14 J/m^2 Air	van Osdell 2002
Staphylococcus epidermis	29 J/m^2 Air	van Osdell 2002
Staphylococcus epidermis	20 J/m^2 Air	Nakamura 1987
Staphylococcus epidermis	22 J/m^2 Air	Furuhashi 1989
Streptococcus agalactiae	5 J/m^2 Air	Luckiesh 1949
Streptococcus haemolyticus	22 J/m^2 Surface	Sharp 1939
Streptococcus pneumoniae	468 J/m^2 Surface	Gritz 1990
Streptococcus pyogenes	4 J/m^2 Surface	Lidwell 1950
Streptococcus pyogenes	1 J/m^2 Air	Luckiesh 1949
Stroptococcus viridans	20 J/m^2 Surface	Sharp 1939
Escherichia coli	25 J/m^2 Surface	Sharp 1939
Escherichia coli	19 J/m^2 Surface	Rentschler 1942
Escherichia coli	12 J/m^2 Surface	Rentschler 1942
Escherichia coli	25 J/m^2 Surface	Rentschler 1941
Escherichia coli	20 J/m^2 Surface	Quek 2008
Escherichia coli	51 J/m^2 Surface	Luckiesh 1949
Escherichia coli	34 J/m^2 Surface	Kim 2002
Escherichia coli	55 J/m^{2}Surface	Hollaender 1955
Escherichia coli	8 J/m^{2}Surface	Collins 1971
Escherichia coli	3 J/m^2 Air	Webb 1970
Escherichia coli	11 J/m^2 Air	Webb 1970
Escherichia coli	11 J/m^2 Air	Rentschler 1942
Escherichia coli	13 J/m^2 Air	Rentschler 1942
Escherichia coli	15 J/m^2 Air	Luckiesh 1949
Escherichia coli	2 J/m^2 Air	Koller 1939
Escherichia coli	11 J/m^2 Air	Koller 1939

(Note: Conversion from J/m^2 to mJ/cm^2 divides by 10)

Opportunistic infections cost hospitals and outpatient medical facilities billions each year in lawsuits, claim settlements, mitigation, insurance, time and resources. Although it has been known that UV-C can deactivate viruses and destroy bacteria, commercial development of a practical UV unit has been slow in development. The SARS-CoV-2 pandemic brought UV to the forefront. Since independent dosimeter tests demonstrate Sterile-Bright® delivers 25mJ/cm^2 UV-C$_{254}$ at 10 feet (~3 meters) in less than 5 minutes, all but Streptococcus pneumoniae would be rendered inert between 60 seconds and three minutes.

Safety

One of the biggest misconceptions regarding UV technologies is that ALL air cleaners utilizing UV and/or ozone are inherently dangerous. The reality is that, when used properly and according to manufacturers' instructions, there seems to be little concern of a serious health risk. In fact, UV light and ozone have the ability to disinfect microorganisms without adding chemical byproducts. Furthermore, ozone is less corrosive to equipment than most chemicals currently being used as disinfectants, such as chlorine.

The reason for Sterile-Bright® safety precautions, such as restricting use of the units to unoccupied spaces, is because ozone cannot differentiate between harmful pathogens and humans and can, in excessive amounts, oxidize us. High level ozone exposure to humans can produce side effects such as coughing, throat irritation, and/or experiencing an uncomfortable sensation in the chest.

There are currently additional Sterile-Bright® studies underway by leading experts. The studies focus on safety, indoor air quality, as well as efficacy in killing new viruses, such as SARS-CoV-2 and/or surrogate viruses.

Summary and Recommendations

UV light technology, specifically the Sterile-Bright® technology, has the potential to be an important tool for indoor aerial disinfection during the current pandemic and beyond. The Sterile-Bright® units provide dual-action (broad spectrum UV light plus ozone), effective, fast and convenient disinfection. The units are portable and only require a minimal amount of time to treat the average room. In addition, the UV light plus ozone gas can give complete coverage of all surfaces, including those that are difficult to access through disinfectant wipes and sprays. Finally, Sterile-Bright® units have an excellent value proposition. Each unit has an average life cycle of 100,000-hours and they are significantly lower in cost relative to the Xenex® pulsed xenon robot and other technologies. The Sterile-Bright® technology applies proven scientific concepts to address global public health and make our surroundings cleaner and safer.

**White Paper Author Dr. Sung earned her Ph.D. in physical chemistry at Harvard University under Professor Dudley Herschbach (1986 Nobel Laureate in Chemistry). Dr. Sung was a National Science Pre-Doctoral Fellow as well as a NATO Postdoctoral Fellow at Harvard University. The bulk of Dr. Sung's career has been in C-level positions at life science companies. She is currently serving as Chief Business Officer of AEGEA Biotechnologies, a private company developing next generation molecular diagnostic tests for SARS-CoV-2, and she is passionate about identifying and applying the best science to address the global health pandemic. Dr. Stella M. Sung can be contacted at smsung@post.harvard.edu or ssung@aegeabiotech.com.*

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