

3M Optical Systems Division
3M™ Air Guide Value Proposition



Create Visions
of Wonder



Contents

LED backlight design innovation	3
LED backlight architecture—a comparison.....	3
How the Air Guide design works.....	4
Key Feature Comparison	5
A breakthrough in light mixing	5
How light mixing benefits system-level costs and performance	6
Reducing the cost of displays to the consumer	8
A step change improvement in environmental impact.....	10
Conclusion.....	10
Recap: Air Guide advantages.....	10
References	11

LED backlight design innovation

LED backlights are slender, sleek, and standard technology for a host of popular devices, including laptops, tablets, smart phones, televisions, and digital signage. Their ubiquitous use, however, has consequences. Current LED backlight designs are complex, costly, and generate hundreds of millions of pounds of plastic waste every year.

This white paper introduces an innovative and sustainable alternative—the 3M Air Guide. The Air Guide is a radical development in LED backlight design. Unlike current backlights, which require multiple films and a solid light guide to spread light from multiple LEDs, the new design uses a hollow cavity with no free-floating films and no solid light guide. In the Air Guide design, light is spread unobstructed through the air of the cavity between the LCD panel and the chassis.

The core innovation of the Air Guide design is a new class of optical film that 3M calls *Collimating Multilayer Optical Film, or CMOF*. CMOF combines two types of nanotechnologies: nanolayer optics and ultra-low refractive index nanofoam. The CMOF film is attached directly to the LCD panel, replacing several separate films used in current LED backlight designs. The only other film component is a highly efficient back reflector, 3M's ESR film, which is mounted on the chassis. ESR film is used in current backlight design.¹⁻³

The Air Guide design greatly reduces the number of components and the weight of the backlight. It also provides multiple opportunities for cost reduction—from material, inventory, and transportation costs, to simplification of design, inspection, and assembly.

From a performance standpoint, the Air Guide design is efficient and exceeds current designs in viewing angle, which is of particular importance to televisions and digital signage. The Air Guide design has superior light mixing capability, which allows manufacturers to reduce the number of LEDs by as much as 80 percent, and use less stringent specifications governing LED color and brightness variation. The Air Guide also creates new display design possibilities, including zero bezel on three sides, reduced weight, and an elegant simplicity.

In addition to cost and performance advantages, the Air Guide design allows display manufacturers to make a significant improvement in the environmental profile of their products by producing displays that operate efficiently on fewer LEDs, and require less plastic. It is estimated that the Air Guide design would directly eliminate over 900 hundred million pounds of plastic from the waste stream.

LED backlight architecture—a comparison

The conventional LCD backlight architecture is shown on the left. It consists of a back reflector mounted on the chassis, followed by a solid light guide, one or more diffuser and prism films, and a reflective polarizer. The final element is the LCD panel.

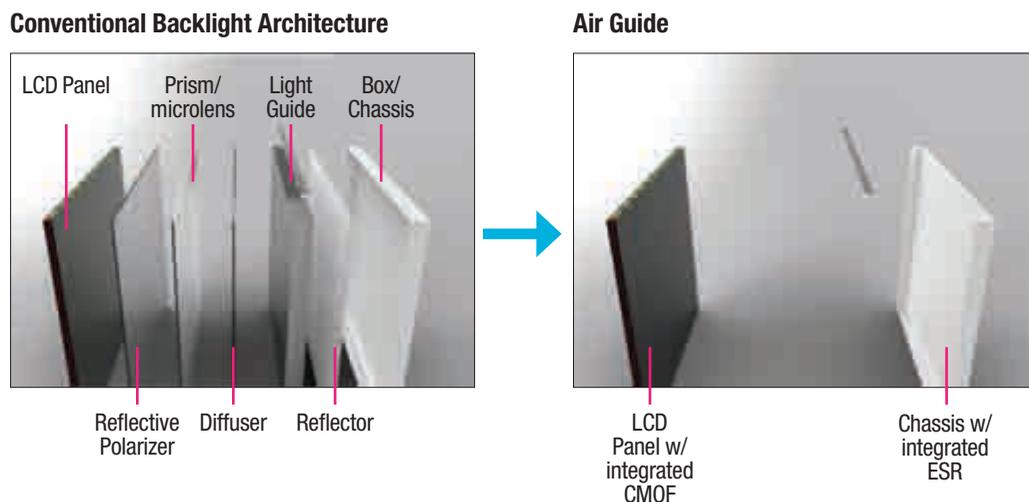


Illustration 1. Conventional versus Air Guide backlight architectures

The Air Guide architecture is shown on the right. It consists of a single CMOF film integrated with the LCD panel and an ESR back reflector film mounted on the chassis. These two films serve as the reflective boundaries of the air cavity where light is introduced. Freestanding films, including diffuser films, prism films, reflective polarizer, and solid light guide are completely eliminated. The Air Guide LEDs are positioned at one or more edges of the hollow air cavity, where they inject collimated light between the LED panel and the back reflector. External optics or lenses can be used, but no special LEDs are required. The non-illuminated edges of the chassis are highly reflective with minimal gaps, which provides for a highly efficient optical cavity. Single-edge illumination is shown, but the architecture also accommodates two-, three-, or four-edge illumination.

How the Air Guide design works

The heart of the Air Guide design is 3M's collimating multilayer optical film (CMOF), a new class of optical film that provides several functions in one, including diffuser, prism/microlens, and reflective polarizer. Paired with 3M's ESR film as the back reflector, it also serves as the solid light guide. For the first time, LCDs with completely integrated optics are possible using the CMOF film.

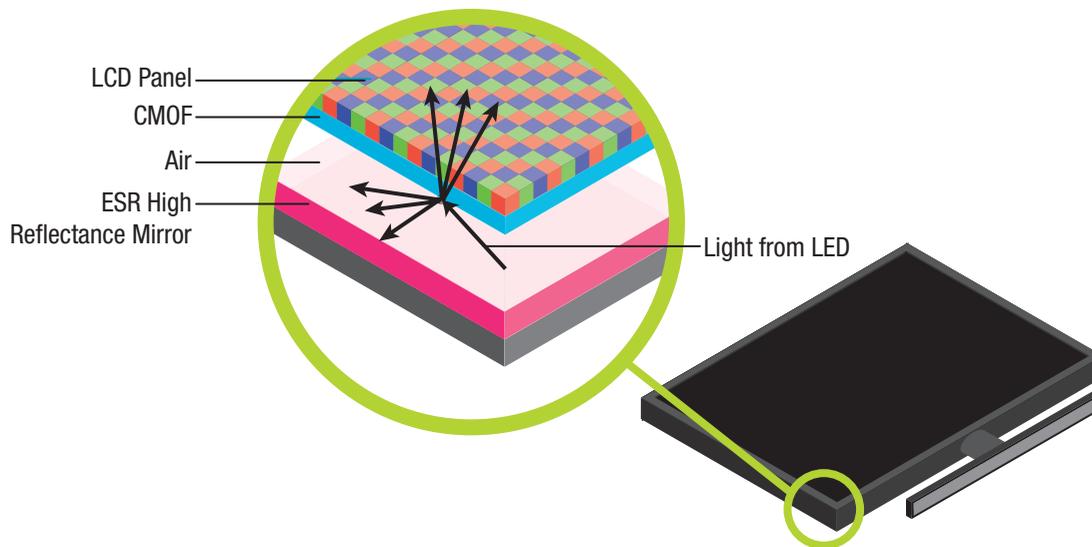


Illustration 2. Air Guide light transport and emission



3M's Multilayer Optical Film technology, featured in the journal *Science*⁴

An important function of the CMOF film is that it imparts a semi-specular (or forward scattering) distribution of reflected light in the Air Guide cavity. This enhances the light mixing and uniformity of the system.

Light from LEDs positioned at the edge is injected into the cavity and is transported forward by multiple reflections. Each cycle of reflection propagates the light within the cavity and transmits a portion of the light through the CMOF film to the LCD panel and the viewer. CMOF reflectance is angle selective, which contributes to light transport and viewing angle control.

The back reflector is 3M™ Enhanced Specular Reflector (ESR). This multilayer film, which is more than 98.5 percent reflective at all angles, is the most reflective mirror ever produced. The high level of reflectance is essential in delivering good efficiency and uniformity from the Air Guide's multi-bounce cavity. Lower reflectance materials create absorptive losses, and 'white' reflectors are poor for light transport.

Both CMOF and ESR films are based on 3M's innovative nanolayer birefringent optical film platform.

Key Feature Comparison

Category	Conventional	Air Guide
Number of free floating components	5	0
Weight of Optical Components (Kg) 52" Diagonal Display	3.2	0.2
Minimum number of LEDs based on uniformity spacing limit (52" Dia)	96	19
Sensitivity to LED variation (binning, drift, failure)	High	Low

Chart 1. Key feature comparison, conventional versus Air Guide backlights

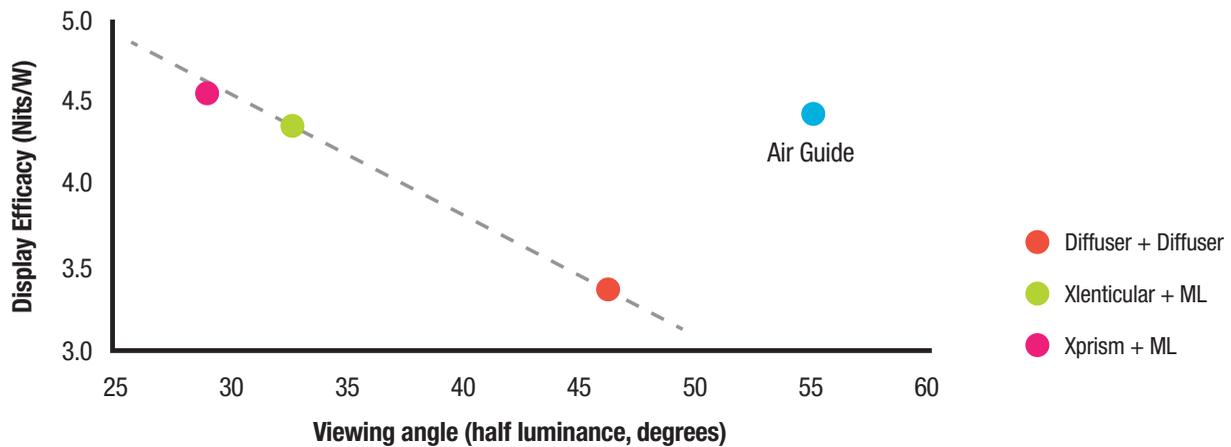


Illustration 4. Efficiency vs. viewing angle for Air Guide and traditional solid light guide systems

The figure above shows a plot of display efficiency and viewing angle half luminance. It is clearly seen that compared to traditional solid light guide systems, the Air Guide is the high efficiency choice for wide viewing angle displays.

A breakthrough in light mixing

Among the most important system-level characteristics of the Air Guide is the dramatic improvement in light mixing. Below are two ray-trace models of light from a single LED injected into a conventional solid light guide (left) and the hollow Air Guide (right).

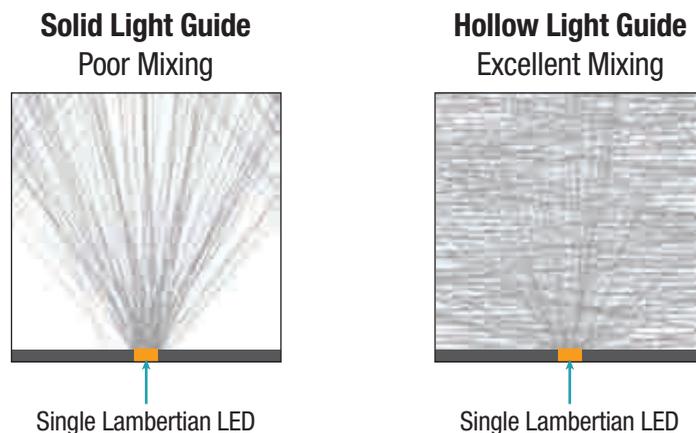


Illustration 5. Light-mixing capabilities, conventional versus Air Guide backlights

When light is injected into a solid light guide, it refracts, which greatly narrows the region of influence. In contrast, a hollow light guide eliminates refraction. Injected light, therefore, has a very broad region of influence as shown in the second ray trace. The photos below show the difference in actual displays. Remarkably, the Air Guide eliminates headlighting at 60 mm LED spacing. The typical uniformity limit for a solid light guide is about 12 mm. Due to the expansion of the LED uniformity spacing limit, the Air Guide enables manufacturers to produce displays with 80 percent fewer LEDs.

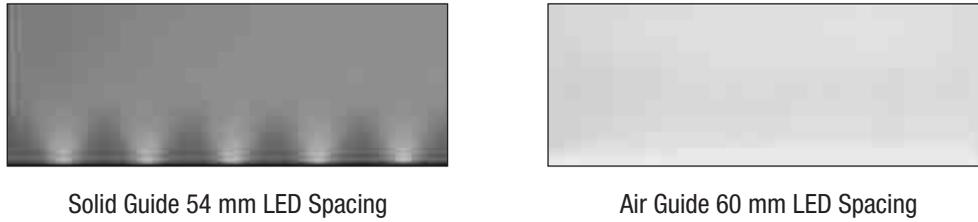


Illustration 6. Headlighting, conventional versus Air Guide backlights

We anticipate that subsequent generations of CMOF will permit even greater LED spacing without loss of uniformity, allowing backlight manufacturers to make even greater improvements in LED efficiency.

As the chart on the following page demonstrates, the Air Guide's superior light mixing provides multiple cost and system-level performance advantages, from reducing the total number of LEDs to enabling robust systems that are tolerant to variations in LED color or brightness. Superior light mixing also means that displays based on the Air Guide design can tolerate the outright failure of up to 80 percent of the LEDs in a given display.

How light mixing benefits system-level costs and performance

Use of Light Mixing:

Cost down by increased LED spacing



Comment:

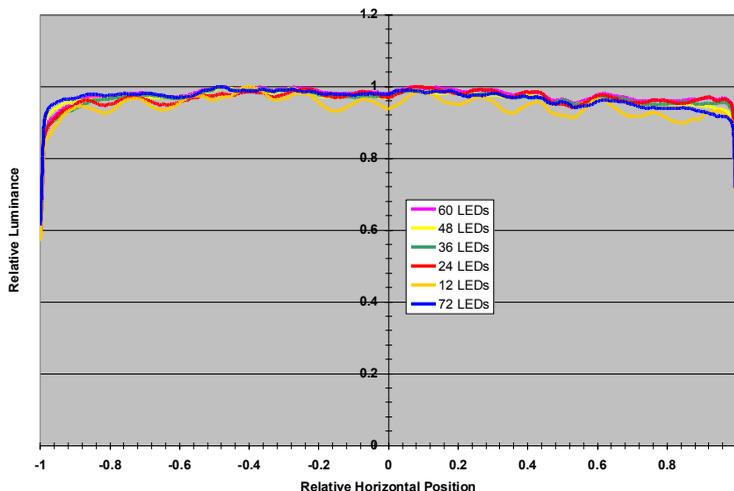
Typical solid guides have spacing limit of 12 mm. Air Guides have demonstrated 60 mm.

Benefit:

- Costs down
- Fewer LEDs
- Enables use of higher power LEDs

Use of Light Mixing:

Robust to LED variation, drift or failure



Air Guide Uniformity with 0 to 80% LED failure

Comment:

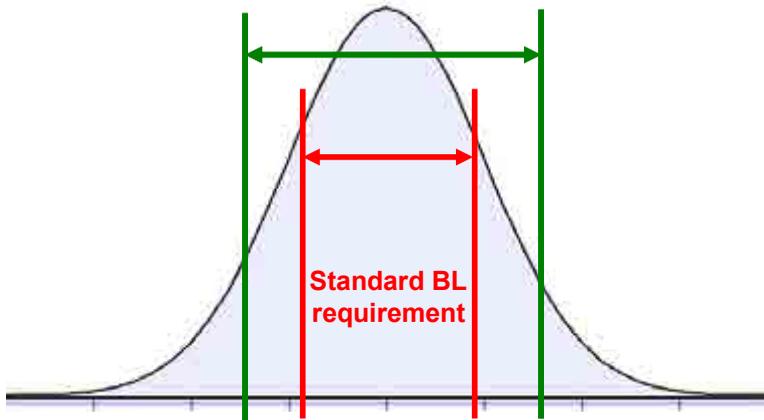
Air Guide demonstrated still uniform even when 80% of LEDs fail.

Benefit:

- Reduced warranty costs
- System reliability

Use of Light Mixing:

Tolerant to wider bin ranges



LED Production Process

Comment:

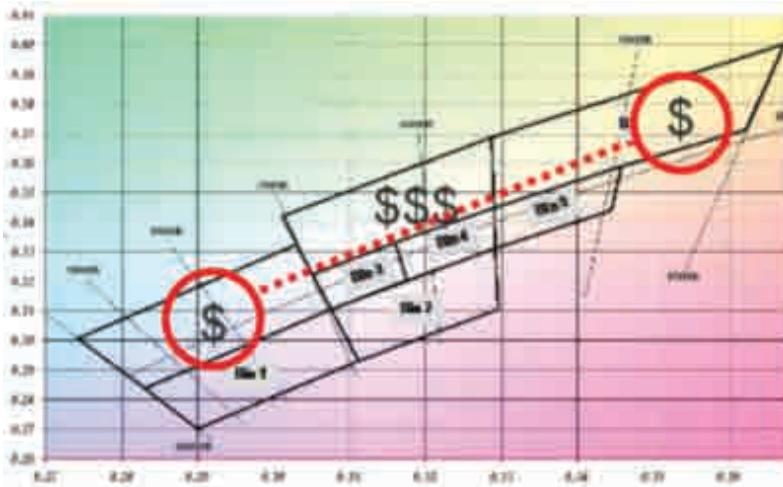
Large variations of individual LEDs average out by light mixing with other LEDs.

Benefit:

- Cost down
- Reduce or eliminate LED binning
- Full LED utilization
- Reduce need for additional LED capacity investment

Use of Light Mixing:

Mix different bins or types of LEDs. Avoid costly bins if desired.



Example LED Binning Map w/hypothetical costs

Comment:

Avoid high cost bins, high LED utilization, reduced binning costs.

Benefit:

- Cost down
- Full LED utilization
- Novel system architectures

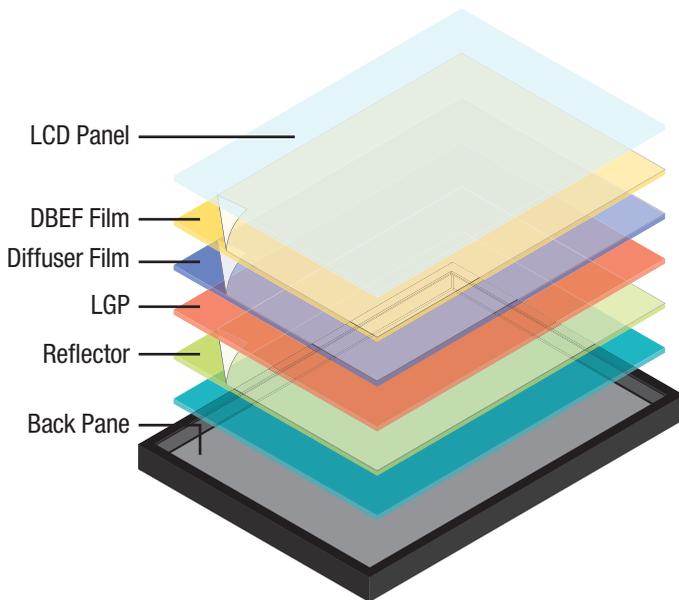
Reducing the cost of displays to the consumer

The ultimate goal of consumer electronics is cost reduction to the end user. Conventional backlight systems greatly limit the opportunities for reducing those costs.

Because of their limited light-mixing capabilities, conventional backlight systems can only achieve adequate uniformity through close spacing of LEDs, and the color or brightness of the light from these LEDs must fall within tight specifications. Manufacturers incur costs for sorting and binning large quantities of LEDs by color and brightness, which can account for 30 percent of the total LED cost.⁵ Additional expense comes from multiple light-management films and solid light guide. In contrast, the Air Guide design can relieve these fundamental constraints and enable multiple opportunities for non-incremental cost reduction. Lastly, factory efficiencies can be improved because of the increased simplicity of inspection, handling, and assembly. (Illustration 7).

Factory Today

Multiple materials, inspections, assembly steps, waste sources



New Era Factory

Simplified inspection, simplified assembly, minimum waste

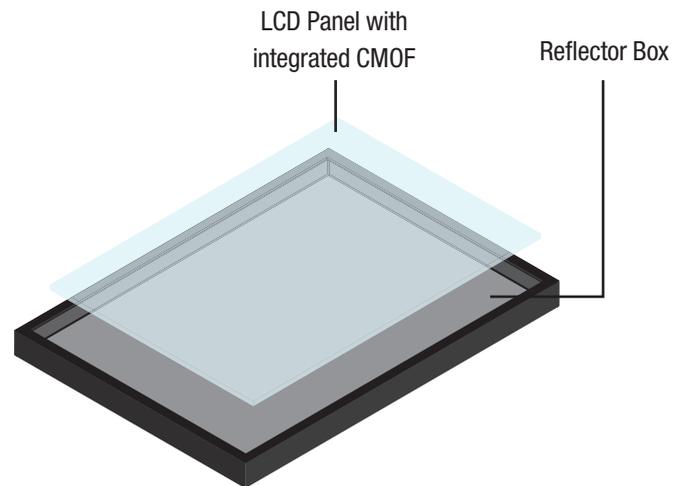
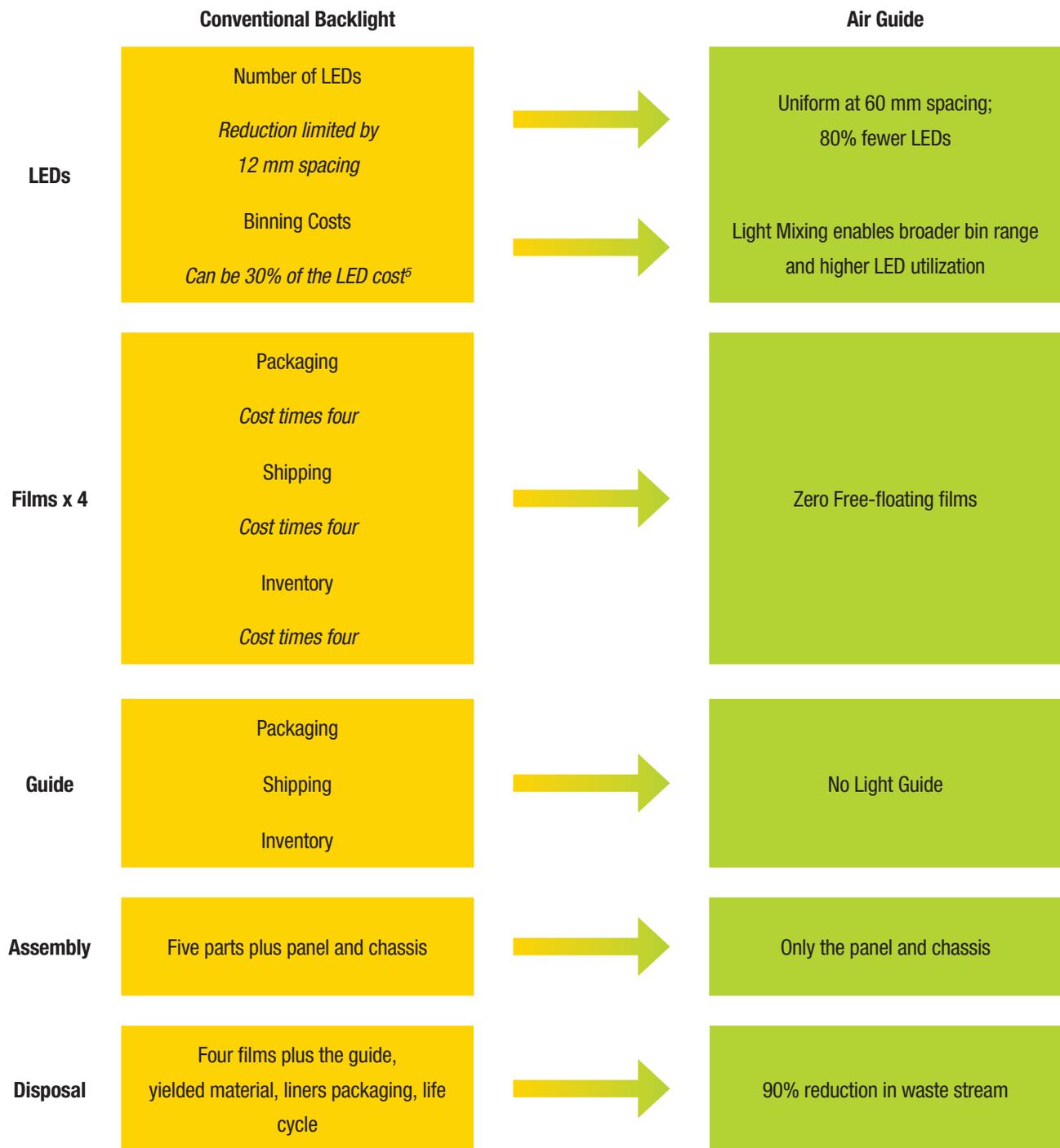


Illustration 7. Manufacturing efficiencies, conventional versus Air Guide backlights

As a result, systemic and even hidden costs associated with the manufacture of a conventional light-guide system, such as packaging, shipping, inventory and inspection of components, LED binning, backlight assembly, and disposal can be fundamentally addressed. (See chart 3.)

Chart 3. The components of cost to the consumer.
 How Air Guide relieves cost constraints of conventional solid light-guide systems.



The Air Guide design is scalable and flexible. It can be applied to multiple types and sizes of displays, from small monitors to large consumer televisions and digital signs. Furthermore, it removes concerns over the availability of raw materials, such as the PMMA used in solid light guides.⁶⁻⁷ components. The elimination of the solid light guide and the multiple “free-floating” films—the diffuser film(s), prism film(s), and a reflective polarizer—will allow those manufacturers to reduce their plastic use by some 90 percent. That means an order of magnitude of plastic can be eliminated from the waste stream by the adoption of this radically simple and more effective design.

A step change improvement in environmental impact

In addition to its numerous cost-reduction opportunities and performance attributes, the Air Guide design gives manufacturers an opportunity to make a remarkable improvement in the environmental profile of their products.

- **LED reduction:** Superior light mixing allows an up to 80 percent non-incremental reduction in the number of LEDs. To achieve a level of brightness comparable with current backlights, a smaller number of LEDs would need to be brighter, but this is consistent with industry trends. We note the availability of 1000 Lumen LEDs, a handful of which produce enough light to light a television.^{8,9}
- **Waste stream:** Today, display manufacturers use approximately 1 billion pounds of plastic in their display optical components. The elimination of the solid light guide and the multiple free-floating films—diffuser films, prism films, and reflective polarizer—will allow manufacturers to reduce their plastic use by an estimated 90 percent. That means an order of magnitude of plastic can be eliminated from the waste stream by the adoption of this radically simple design.
- **Carbon footprint:** A full accounting of environmental impact takes into account not only the waste stream of materials, but also the shipping, packaging (including liners), and transportation required to move materials by land, sea, and air. The elimination of the solid light guide and associated free-floating films will greatly reduce these life-cycle management issues for displays.

Conclusion

3M's new class of optical film, known as Collimating Multilayer Optical Film, or CMOF, is a single film that combines polarizing, collimating, and diffusing functions, and can be attached directly to an LCD panel. This integration has enabled a radically simple backlight design with a hollow cavity that eliminates much of the complexity found in conventional backlight systems. The Air Guide's simpler design reduces the number of components (up to 80 percent fewer LEDs, the light guide, and all free-floating films), the cost of manufacturing, the environmental impact (the elimination of an estimated 900 million pounds of plastic from the waste stream), and reduces the overall environmental profile of LCDs.^{10,11}

The superior light-mixing capabilities of the Air Guide design provides distinct system-level benefits, including improved LED utilization and improved system robustness to LED variation. We anticipate that subsequent generations of CMOF film will permit even wider spacing without loss of uniformity, which will allow backlight manufacturers to take increasing advantage of improvements in LED efficiency.

Recap: Air Guide advantages

- **Cost reduction:** Fewer components, fewer LEDs, fewer inspection steps, streamlined operations
- **Waste stream reduction:** Reduces the amount of plastic in the backlight by 90 percent
- **Reduced LED count:** A non-incremental reduction (approximately 80 percent) in number of LEDs by increased LED spacing uniformity limits
- **Robustness/warranty:** A binning-tolerant, failure-tolerant, robust design
- **Energy efficiency:** Energy Star compatible
- **Broad viewing angle:** Suitable for television or digital signage
- **Scalable:** From small monitors to televisions to large digital signage
- **Manufacturing flexibility:** An LCD panel containing CMOF film can be used on multiple types and sizes of displays. Concerns over raw material availability (such as PMMA for solid light guides) are eliminated. Assembly time is reduced.
- **Number of SKUs:** The inspection, handling, waste, and assembly of multiple films and the light guide are eliminated. The Air Guide design has only the LED panel/CMOF film unit and the reflector box.
- **Zero-bezel styling:** Single edge, bottom illumination enables zero bezel on three sides.
- **Weight Reduction:** Removal of the solid light guide and free-floating films reduces weight by several kilograms in large sets.

References:

1. T. Liu et. al., SID '09 Digest, 55.1, "Edge-lit Hollow Backlight Using Tunable Reflective Polarizer for LCD Displays."
2. J. Wheatley et. al., Optics Express, Vol. 17, 2009, "Efficient LED Light Distribution Cavities using Low Loss, Angle-Selective Interference Transflectors."
3. J. Wheatley et. al, SID '11 Digest, 60.1, "LCD Integrated Optics."
4. M. Weber, et. al., Science, March 2000: Vol. 287 no. 5462 pp. 2451-2456.
5. Electronic Component News, Joe DeNicholas, National Semiconductor, November 9, 2010, <http://www.ecnmag.com/Articles/2010/11/App-Solutions/driving-LEDs/> .
6. Display Search Quarterly LCD Value Chain Report, Dec. 2010.
7. "LGP for LED LCD TV," October, 2011, Display Bank Co. Ltd.
8. LEDs Magazine, "Cree launches new LED components, arrays, and modules," April 18, 2011.
9. Cree XLamp® XM-L LEDs Product Family Data Sheet, CLD-DS33 REV 2, Cree, Inc.
10. Jong Sung Song, KunMo Lee, Resources, Conservation and Recycling 54 (2010), 547–556, "Development of a low carbon product design system based on embedded GHG emissions."
11. 3M White Paper on Sustainability, 2011.



3M Optical Systems Division
3M Center, Building 235-1E-54
St. Paul, MN 55144-1000
U.S.A.

3M is a trademark of 3M company.
© 3M 2011. All rights reserved.
Please recycle.
Printed in USA dez12026



Requester: Morgan Berg
Creator: deZinnia
File Name: dez12026_AirGuideWP.indd
Date: 5/6/11

Printed Colors – Front:



Printed Colors – Back:



Match Colors:



Scale:  1 Inch

**This artwork has been created as requested by 3M.
3M is responsible for the artwork AS APPROVED and
assumes full responsibility for its correctness.**