PikeResearch
Cleantech Market Intelligence

Research Report

Energy Efficient Displays for Mobile Devices

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Section 1

EXECUTIVE SUMMARY

The electronics industry has embraced the concepts and processes of “green” and “sustainability” to enhance their products, driven by corporate environmental programs, government regulation, and customer demand. New and existing products and processes in all industry sectors are being evaluated and continuously improved with the goals of better energy efficiency, reduced greenhouse gas (GHG) emissions, and less waste of renewable and non-renewable resources. The electronics industry in general and the mobile device sector in particular have been very active in making improvements to their products and processes.

Every step in a green and sustainable process has environmental impacts, and the impact of product performance is the most important because it has such a strong influence on the customer experience. However, the number of processes required to make a green and sustainable product and the cross-boundary interactions of these processes are extremely complex. Green and sustainable processes for component suppliers such as display manufacturers include the following key elements:

- A foundation in Design for the Environment (DfE) and ISO 9000 and 14000 registration.
- A complete lifecycle analysis (LCA), which includes the environmental impacts of raw materials extraction, manufacturing & assembly, product performance, ancillary equipment & packaging, followed by shipping methods and distance to an OEM assembly site.
- Once a baseline degree of green and sustainability is established, all of the processes must go through periodic cycles of continuous improvement.

The display in a mobile device is the primary user interface and its performance has a significant effect on the device’s battery life. If all of the estimated 4 billion mobile device subscribers in 2008 that had transmissive (LCD) or emissive (OLED) displays were instead using an energy-efficient reflective display, Pike Research estimates that the energy saved while the device is active would be 2.4 terawatt hours (TWh) per year.

Improving energy efficiency is an essential first step in creating greener mobile devices. Pike Research’s analysis indicates that reflective display technologies such as interferometric modulator displays (IMOD) provide a significant energy efficiency advantage over incumbent technologies such as LCD or OLED.

In our analysis, a mobile device using an IMOD display would consume 33.7% less energy, which extends the battery life by 51%, when compared with a similar mobile device that uses a conventional LCD display. Based on a simple lifecycle analysis, this would result in 94% less carbon dioxide emitted in the use phase for the display. In addition, this efficiency advantage results in about 58 fewer recharge cycles over the course of a year and would extend the life of the battery for an additional 1.25 years.

Pike Research estimates that reflective display technology could capture greater than 20% market share in mini-display sizes between 2.5 and 10 inches over the next five years with an increasing percentage over time if the operational characteristics of the displays are perceived, first by OEMs and then by potential customers, as equivalent to an LCD.

Section 2

HOW GREEN ARE MOBILE DEVICES?

2.1 Introduction

So what does it mean to have a green and/or sustainable display technology?

Starting with a high-level perspective, Pike Research defines **“green electronics”** produced by OEMs as a process of tradeoffs, throughout their supply chain, that optimizes corporate strategy, competitive analyses, product development, manufacturing, marketing, sales, and end-of-life management. These tradeoffs minimize the environmental impact of a product.

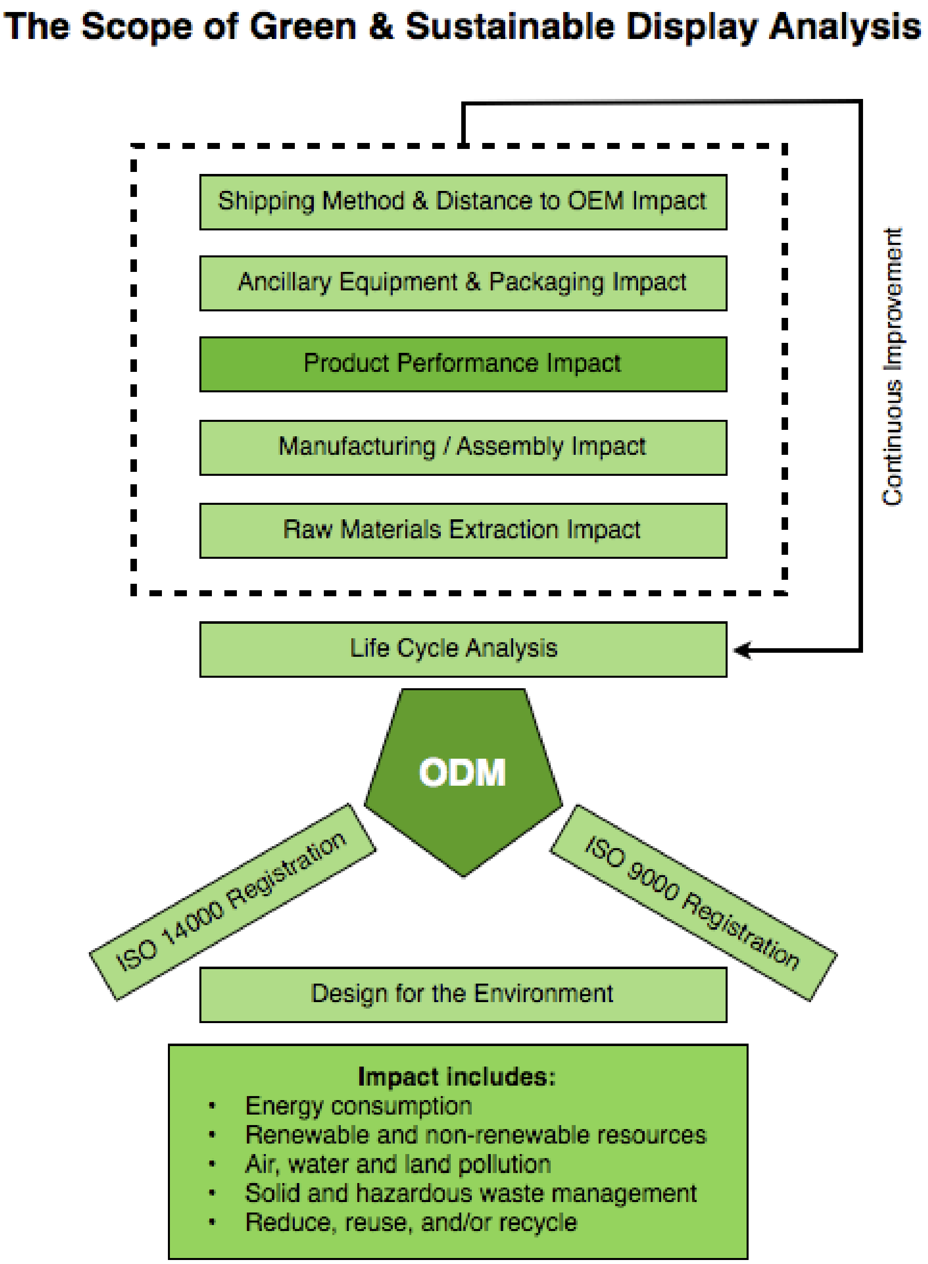
Sustainability is defined as a management system that evaluates the impact to natural resources as well as goods and services produced, which promotes reduced consumption, using renewable resources where possible and promoting processes and products that minimize the amount and effect of extraction and maximize resource utilization efficiency.

Focusing on the component supplier segment, Pike Research then defines **green display technology** as the combination of materials and methods that results in the lowest possible power consumption for a given display size while minimizing the environmental impact of its raw materials, components, production processes, distribution, and end-of-life reuse, recyclability or disposal.

The analysis that follows in Section 3 is specific to the Product Performance Impacts of a display as shown in Figure 2.1 below. Pike Research believes this is the best use of a component supplier’s efforts to gain the support and generate interest from OEMs because it demonstrates significant progress in addressing issues with the power budget in displays currently dominated by LCD technology.

In the short term, the power consumption advantage of reflective display technologies while in operation will dominate IMOD’s positive contributions to green and sustainability efforts because of the inherent technology characteristics. In the future, using a Design for the Environment (DfE) process that begins to include the other elements in a lifecycle analysis can reduce the carbon footprint of a product or process even further. Longer term, ISO registration and a complete lifecycle analysis (LCA) incorporating raw materials extraction, all manufacturing processes, transportation and waste management will be necessary to completely evaluate the degree of green and sustainability of the supply chain for displays. Once a baseline is established goals and continuous improvement cycles can be used to measure progress.

Figure 2.1 *Steps in Evaluating the Degree of Green and Sustainability in a Display*



(Source: Pike Research)

2.2 How Green is Green?

Every product and every process is different, and both "green" and "sustainable" are variables evaluated by continuous improvement processes, but in general Pike Research considers the following conditions when analyzing green products:

- If a manufacturing process is audited by a third party to an international standard that quantifies green and sustainability attributes, then the product(s) produced have established a green baseline from which continuous improvements can be made.
- If a product has an attribute like lower power consumption, then energy is saved, but it does not necessarily mean that the underlying processes that produced the energy savings also have green or sustainable characteristics.
- If one or more components in a product are green and sustainable, the display for example, then they contribute to the overall 'greenness' of the product, but do not, in and of themselves, make a product green. OEMs typically challenge their suppliers to contribute to improvement objectives and components like displays that impact the power budget are a top priority.

The motivation to produce a product or provide a service is based on a company's analysis of customer needs and wants that can be translated into a new or modified product based on the technology available, which will also create something new or differentiate them from a competitor. The big mobile device manufacturers will benefit from developing and selling green and sustainable products only to the degree that they are accepted in the marketplace and perceived as attractive by consumers when compared with other competitive offerings. The goal remains to make money, now and in the future. Each of these companies has a well documented and mature sustainability or corporate citizenship process because of compliance with government regulations and it is a factor that some consumers consider in today's marketplace.

2.2.1 Consumer Attitudes toward Green Products

A Pew Research consumer survey completed annually in January since 2001 shows that protecting the environment (which includes, but is not limited to being green or sustainable) is one of the top 20 policy priorities. In Pew's 2009 survey, environmental protection was in 17th place among all the priorities, with about 41% of respondents stating it is a top priority. The economy and jobs occupy the top two spots in the survey at more than 80%. With the worsening economy, environmental support has dropped 15 percentage points since the 2008 survey and the decline cuts across all age groups and education levels.

Table 2.1 Percent of Survey Respondents Who Say Protecting the Environment is a Top Priority

2001	2002	2003	2004	2005	2006	2007	2008	2009
63%	44%	39%	49%	49%	57%	57%	56%	41%

(Source: Pew Research)

Karran Finlay, a green marketing expert and president of Karran Finlay Marketing in Vancouver, says most environmentalists would be receptive to any idea that results in increased conservation efforts, regardless of consumers' motives. "Marketers and business owners have the power to persuade consumers through competitive altruism, driving them toward more environmentally sustainable products," he says. "It becomes a win-win situation for profits and the planet."

2.3 What Will Consumers Buy?

Green and Sustainability also have economic benefits. Consumer surveys (National Marketing Institute, 2007 LOHAS) indicated that 61% of respondents care about the environment, but purchases are determined mainly by price. Also consumers are 58% more likely to buy products from companies that can demonstrate a positive impact on the environment. However, only 30% indicated a willingness to pay up to 20% more for environmentally friendly and sustainable products.

2.4 Display Lifecycle Analysis Results

Pike Research completed a simple and high level lifecycle analysis of LCD and IMOD display technology using the LCA calculator from Industrial Design Consultancy Ltd. Based on the consumption values used, the environmental impact of IMOD is 95% less than an LCD of the same size.

Table 2.2 Simple Lifecycle Analysis and Parameters, LCD vs. IMOD Displays

Description	LCD	IMOD
Power Consumption by One Display	274 mW	14 mW
Environmental Impact		
Energy	5.9 MJ	.3 MJ
Carbon Dioxide (CO_2) Emissions	2.4 kg	.12 kg
Extraction and Manufacturing	14 kg CO_2	
Transport (by sea from Asia to N. America)	30 kg CO_2	
Disposal (15% recycle rate)	0.26 kg CO_2	

(Source: Pike Research)

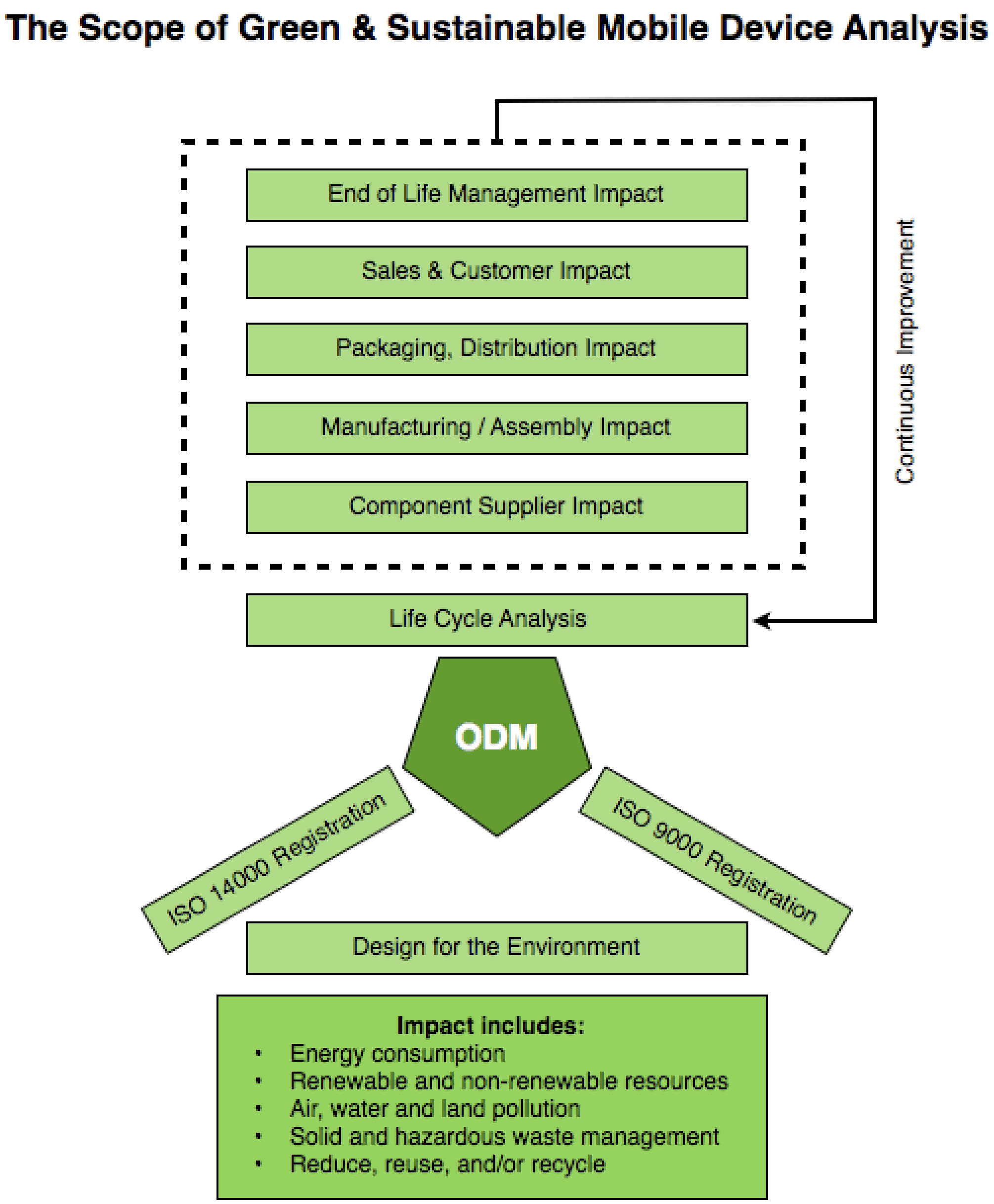
Data for three of the four major categories in a typical LCA (extraction and manufacturing, transportation and disposal) were held constant at assumed values because data was not available for LCDs and a complete LCA for IMOD has not been completed. The remaining variable, “Use”, was based on the daily weighted average of power consumed by the display and backlight in an LCD and display and frontlight in an IMOD adjusted for the operating assumptions in Table 3.2 below and for the percent active time in the usage model. Other parameters included a two year lifetime with the display operating three hours per day and seven days per week and assuming the display was otherwise in standby.

2.5 OEM Lifecycle Analysis Attributes

All of the top five mobile phone OEMs have established green / sustainability programs that are monitored and improved on an annual basis. Component suppliers like display manufacturers are captured by these initiatives via these corporation’s supply chain management processes. Typically suppliers are given targets for improvements in key areas like energy efficiency, carbon footprint, recycling and waste management.

Figure 2.2 shows how component suppliers fit into the supply chain life cycle analysis evaluated by OEMs.

Figure 2.2 Component Supplier's Contribution to an OEM's Life Cycle Analysis



Impact includes:

- Energy consumption
- Renewable and non-renewable resources
- Air, water and land pollution
- Solid and hazardous waste management
- Reduce, reuse, and/or recycle

(Source: Pike Research)

Section 3

DISPLAY TECHNOLOGY ANALYSIS

3.1 Objective

Compare the power consumption characteristics of transmissive (LCD) and reflective displays (IMOD) with diagonal dimensions of 2.4 to 2.8 inches using typical daily usage models.

3.2 Value Proposition

Displays with demonstrable energy efficiencies offer the following advantages:

- Increased energy efficiency during operation extends the time between battery recharges for customers reducing idle time.
- Fewer recharge cycles are required, which results in a reduction to the energy grid when applied to the four billion subscribers worldwide.
- In addition, the reduced number of recharging cycles can extend the life of the device beyond the typical two year exchange cycle as well as reduce the number of devices sent to landfill disposal.

3.3 Introduction to Comparative Analysis

LCDs in transmissive (roughly 60%) and transflective (roughly 40%) formats are the current industry standard with greater than 95% market share of the mobile display market. OLEDs and several other display technologies used in special or unique environments comprise the rest of the mobile device market. These technologies have set a standard for viewing experience (color reproduction, brightness) indoors and at night with limitations to the viewing experience in bright daylight. Consumers have accepted these capabilities and adapted their usage patterns despite the fact that many of them do not have a good understanding of the impact of these technologies on the environment. Both LCD and OLED display technology consume significant amounts of battery capacity to generate light internally. Unfortunately only about 5-10% of the light generated for a typical LCD actually reaches the viewer's eye. The rest is lost in polarization, color filters, or inefficiencies in the light emitting diodes themselves.

Until now there have been few, if any, alternatives. In Pike Research's opinion, the availability of reflective display technology currently deployed in the e-reader segment and new competitors with different reflective techniques will offer more energy efficient solutions to mobile devices that will increase competition and shift the market away from conventional LCD technologies.

Reflective displays are just beginning to enter the volume production phase for mobile devices. For example, Qualcomm MEMS Technologies, Inc. opened a new IMOD fabrication facility for its mirasol® line of color reflective displays in June 2009 and is one of the first companies to bring an energy efficient reflective technology out of a lab development environment. To be competitive and encourage OEMs to adopt reflective technology, manufacturing costs, power consumption, functional capability, and durability/reliability will need to be perceived as equivalent to, or better than, the LCD standard.

3.4 Usage Models

The three simplified usage models shown below provide estimates of the minutes of active battery time to complete common daily activities on a mobile device. More detailed breakouts are available that add resolution, but these more detailed usage models do not, in Pike Research's opinion, significantly affect power consumption when lumped into these categories. Some of the activities missing from these models include downloading and playing games, ringtone downloads, calendar functions, social network interaction, and music downloads. The total for each use model includes 15% periodic "check" time (the display is active while you check your email, calendar etc.) otherwise the device is in standby mode, recharging or off.

Table 3.1 Minutes per Day of Active Device Time by Common Category and Usage Model

Usage Model	Voice	Web Browsing	Video	Messaging	Check Time	Total
Young Adult	20	75	25	100	33	253
Typical	30	30	10	30	15	115
Business	60	60	10	75	31	236

(Source: Pike Research)

3.5 Energy Savings

If every mobile subscriber in 2009 that has a device with an LCD instead had an IMOD reflective display, the estimated amount of energy savings while operating that mobile device is 33.7%, which could extend battery life about 51%. The difference in power consumption for an LCD display and an IMOD, between 2.4 and 2.8 inches, performing common activities in an office environment on a mobile device have been estimated as shown in Table 3.2.

Table 3.2 Power Consumed by Device Subsystems While In Operation (mW)

	Voice		Web Browsing		Video		Messaging	
	LCD	IMOD	LCD	IMOD	LCD	IMOD	LCD	IMOD
Display	79	1	315	23	315	23	315	11
Power Saved by Display (2.5-2.8 inches)		96%		93%		93%		97%
Device Total	747	741	555	280	887	612	370	80
Power Saved by Device		0.8%		49.6%		31.0%		78.4%

Operating Assumptions: 80% active time in an office, 10% in bright light and 10% at night (dim light)

Display power includes the display plus backlight power for an LCD and frontlight power for an IMOD

(Source: Pike Research)

Table 3.3 Estimated Energy Savings of Reflective Displays Used in Mobile Devices

Metric	Result
Subscribers (2008 data), each with one mobile device	4 billion
Annual Energy SAVED, IMOD vs. LCD	2.4 TWh or ~0.2 kWh/unit
Estimated Total Energy Savings IMOD vs. LCD	**33.7%**

(Source: Pike Research)

To estimate the energy savings in mobile device displays, Pike Research assumed that the 4 billion subscribers are normally distributed (bell curve) and assigned 16% to the "Business" and "Young Adult" usage models and 68% to the "Typical" model (see Table 3.1 above). Also, each subscriber has one mobile device and battery capacity averages 950 mAh. The energy saved was estimated based on the energy consumed by each task using the operating assumptions and includes a 33% inefficiency in conversion from line power to DC. In addition, the bright light condition for an LCD assumes the backlight needs to be twice as bright, hence consuming twice as much power. The night (dim light) condition includes front light power for the IMOD and 32% less backlight power for the LCD compared to the office environment. Not shown is mobile device standby power, which was assumed to be 12 mW for the remainder of a day when a device is not active.

3.6 Display Technology Summaries

Displays can be categorized into one of three major types: emissive/transmissive, reflective, and transflective.

3.6.1 Emissive/Transmissive

The dominant display technology used in mobile devices today is an active matrix Liquid Crystal Display (LCDs). LCDs are generally transmissive, meaning that a light source is used behind the display, with the liquid crystal acting as a light switch. It generally consists of two sheets of glass, a thin-film transistor (TFT) backplane and a liquid crystal material sandwiched between the glass. The light source behind the display transmits light through the liquid crystal pixels, polarizers, and color filters, which operate by changing the polarization of the light, with an applied voltage. This requires a constant source of power for the "backlight," regardless of content. In addition, LCD displays requires constant power to frequently refresh the liquid crystal polarization angle, and prevent screen flicker. Modest reductions in power consumption can be made by turning off or dimming the backlight depending on circumstance by using light sensors.

LCDs represent a mature technology. Improvements are being made in an incremental manner to address the power budget issues. Much of the advantage of LCDs derives from the fact that they are a known commodity; the supply chain (OEMs, carriers, and customers) is familiar, as are the price advantages of the technology and characteristics like contrast ratio and color gamut. Disadvantages such as power consumption and the sunlight viewability are also well known. Battery life will continue to be a constraint for LCDs, but users have adapted their daily activities to deal with it.

OLED (Organic Electro-Luminescent or Light Emitting Diode [LED]) Displays are emissive displays, emitting red, green and blue visible light from individual LED structures formed at each pixel. For an active matrix OLED, the same thin-film circuitry that is used in most LCD displays on mobile devices today also controls individual OLED pixels. The transistor controls the current going into each pixel, which controls the brightness. The power of the display is proportional to the overall brightness of the image displayed – a bright white image on an OLED will consume the maximum power, and a dark black image the minimum.

An inherent issue with both emissive (OLED) and transmissive (LCD) displays on mobile devices is that the viewing experience in bright daylight is difficult because the generated light intensity is less than the ambient light intensity of the sun.

3.6.2 Reflective

Electrophoretic displays are bi-stable reflective displays which consist of charged particles encapsulated in a microcapsule suspended in a fluid. A voltage applied across the particles will cause the spheres to move toward their opposite charge. Ambient light entering the display and hitting the spheres that comprise a pixel will either be absorbed or reflected.

An interferometric modulator display (IMOD) is also bi-stable. A flexible thin-film mirror is fabricated on a transparent substrate with an air gap of a few hundred nanometers between the thin film and the substrate. When ambient light enters this cavity and reflects off the mirrors, it constructively interferes. This process selects a particular color that is reflected back to the viewer, depending on the height of the cavity, which matches the wavelength of red, green, or blue light.

A electrowetting display creates an optical switch by using an applied voltage to contract or release a colored oil film immersed in a liquid that is sitting on top of a hydrophobic insulator. It can also use a transparent electrode attached to a white base material.

All reflective display technologies have the drawback of needing a frontlight in very low light conditions like going from a restaurant to a parked car after dark and trying to check your voicemail or email. However, this is a minimal energy loss because of two factors. First, the percentage of time users spend in low light conditions requiring a frontlight is small (we assumed 10% in our model).l. Second, less frontlight brightness is necessary in dark environments to view a reflective display, since there is less competing light in low light conditions.

3.6.3 Transflective

Transflective displays represent a combination of the transmissive and reflective technologies. They were developed in an attempt to overcome the high power consumption of systems with backlights and address the poor image quality in reflective systems when the ambient light is very low. The construction of a transflective display uses a partially transmissive mirror and includes a backlight. When in very low light conditions, the backlight is used and the system is transmissive; when ambient light is high enough, the display functions as reflective. Transflective displays are a compromise, and the resulting image quality can be suboptimal to either enabling technology. Their strength is in applications where the lighting conditions vary over a wide range.

3.7 Display Operating Characteristics

While power consumption is a primary constraint, the competing display technologies all have pluses and minuses in the marketplace. It is Pike Research's opinion that OEMs will embrace reflective technologies because they offer better power value than traditional LCDs. The reflective technologies also provide enhanced viewing capability in bright sunlight.

The two recurring complaints from customers when evaluating their mobile device performance are battery life and the viewing experience of the display. Battery life is a function of the type and duration of activity being completed by the user and remains limited by the capacity of the battery that conforms to the device's form factor constraints. An unknown percentage of users might, however, be willing to sacrifice form factor (ever thinner, lighter, and smaller) to get a device with a second battery or opt for a higher capacity battery if offered by the OEMs.

The other frustration is the viewing experience of an LCD or OLED in bright sunlight, which Pike Research estimated at 10% of the active time. The ambient brightness of sunlight is sufficient to overwhelm the LCD backlight and the OLEDs, resulting in “washout”. Thus, the images or text on the screen can barely be seen. Devices with transflective displays were developed to help resolve this issue in LCDs operating in bright sunlight. Meanwhile, manufacturing modifications have helped make OLEDs more readable. Since the light source for LCDs and OLEDs is internal to the device, there are no significant issues viewing these displays in the dark.

Reflective displays are the opposite; they are very good in bright sunlight but need the help of a frontlight while operating in darkness, also estimated by Pike Research at 10% of the active time.

In our analysis, 80% of the daily operating time is assumed to be in an office environment.

3.8 Mobile Devices, Lab Test Environment, Display Power Data

Independent measurements were performed by Advantage Inc. of Broomfield, Colorado to evaluate display power for two handsets that represent typical 3G feature phones. Current was measured before and after a display timeout occurred. Under these conditions a Nokia N96 device consumed 362 mW and a BlackBerry Bold 228 mW. The average of these two measurements is 295 mW and was the basis for the display consumption in an office environment.

Section 4

MARKET IMPACTS AND CONCLUSIONS

4.1 The Impact of Energy Efficient Displays

The primary beneficiaries of more energy efficient reflective displays are the OEMs. By reducing the power consumption of a display when active, the power budget can provide more battery capacity for enhanced features or extend the time between recharge cycles. In addition, customers benefit from an increase in battery life with the same functionality.

4.2 The Global Impact of Energy Efficient Devices

A mobile device is dependent on battery life, and battery life is strongly influenced by display power consumption. Power consumed is replaced by a charger that is typically plugged into line power (an electrical outlet) full time. The industry is beginning to react to the impact of so-called “vampire” power consumed before and after a device is recharged. New standards for a universal charger and increasing intelligence within a charger, which will significantly reduce if not eliminate the power consumed by an idle charger, will significantly reduce the carbon footprint of the mobile device category. The environmental impact of leaving a device charger plugged in to the wall full time is significant.

An IMOD equipped device will require about 58 fewer recharge cycles per year, which will allow such a device to recharge to 100% capacity for an additional 1.25 years. This is an important attribute of energy efficient displays because of its impact while in use and the reduction in devices thrown away in a given year.

A lithium battery typically lasts about 400 full recharge cycles, which is what was assumed in this simple comparison. In practice the battery recharge cycles are cumulative and the battery will likely last longer since each recharge cycle is less than a full recharge.

The Young Adult, Typical and Business usage models, along with average active time minutes using a 950 mAh battery and data for days between recharges (2.15 for LCD and 3.25 for IMOD), were used to estimate these effects. A 33% efficiency loss converting 120 volts AC into DC was included to calculate the energy consumed.

An estimate of 175 mW was used for the power drain of a charger plugged-in full time, When all chargers consume less than or equal to 30 mW, which is the European Commission’s most efficient energy standard for chargers, there is the potential for an 83% reduction in energy drain from chargers plugged in full time.

A power consuming attribute of some LCD devices is the display remains powered up after a recharge cycle is complete. If a typical user begins a recharge cycle at bedtime and the recharge cycle only takes 2-3 hours the energy grid is impacted.

Table 4.1 Estimated Energy Consumed by Chargers Left Plugged-in

Subscribers (2008 data), normal distribution, LCD display	4 billion
Estimated Energy Consumed, Chargers Plugged In Full Time	17.8 TW-hrs
Additional Energy Consumed IF LCD Stays On After Recharge	3.8 TW-hrs
	Total = 21.6 TWh

(Source: Pike Research)

4.3 Market Projections

Worldwide consumer demand continues to be strong for mobile devices with more features and longer battery life. Sales in this sector are projected to increase at an 8.5% compound annual growth rate (CAGR) through 2013, when an estimated 1.6 billion units will be produced. The percentage of smartphones is expected to rise more quickly than other mobile devices. Indeed, the market may reach a point where finding a simple, standalone cell phone is difficult, if not impossible.

There were approximately 4 billion mobile subscribers worldwide in 2008 with a penetration rate estimated at 63%. Subscriptions in developed countries are approaching 100%, indicating that an increasing percentage of high-end subscribers have multiple accounts. In developing countries, subscriptions have reached a penetration rate of greater than 50% with a CAGR approaching 33% over the last 6 years. Significant additional potential for growth still exists in countries such as India and China due to their large populations. Opportunities also abound in other developing regions, such as Africa, South America, and additional parts of Asia. Moreover, a spike in demand may occur when the current global economic crisis eases in 2011.

Mobile service contracts typically expire on a 1- or 2-year cycle and customers are encouraged to upgrade to newer models with more features.

4.4 Conclusions

Based on our analysis, Pike Research concludes that a mobile device with a reflective display technology such as IMOD has a 33.7% energy efficiency advantage over the industry standard LCD which extends battery life about 51% when operating in accordance with the usage model. Comparing just the display technologies, IMOD consumes between 86% and 98% less power than an LCD while in operation depending on the task being performed. In terms of energy consumption and carbon dioxide emissions, a simple lifecycle analysis estimated a 94% reduction in environmental impact during the use phase of the display with major contributors' raw materials, manufacturing, transportation and disposal held constant. Reflective displays can contribute to enhanced functionality in mobile devices and reduce the magnitude of the power gap, which provide OEMs substantial incentives to adopt a reflective display technology.

Energy efficiency advantages in the display are an essential first step in increasing the degree of green and sustainability in a mobile device. Although the display alone cannot make a product green or sustainable, energy efficiency improvements are a solid foundation on which manufacturers can build additional sustainability initiatives. In addition to the societal benefits of green and sustainable products, research indicates that consumers are more likely to purchase products that can demonstrate a positive impact on the environment, which will provide additional motivation for manufacturers to drive toward greener mobile devices, beginning with improvements in energy efficiency.

LCDs have a significant market share throughout the full range of display sizes – from handsets up through netbooks, laptops, desktops, and large TVs. However, power consumption increases in all types of displays as the display area increases. The lower battery power requirements for reflective displays should provide growth opportunities for IMOD reflective technology in the full range of mini-display sizes between 2.5 and 10 inches.

Section 5

ACRONYM AND ABBREVIATION LIST

Active Matrix	AM
Average	avg
Bill of Materials	BOM
Bitmap	BMP
Compound Annual Growth Rate	CAGR
Design for Manufacturability	DFM
Design for the Environment	DfE
Electrophoretic Display	EPD
Electrowetting Display	EWD
Gigawatt hours	GWh
Hertz	Hz
Hours	hrs
Interferometric Modular Display	IMOD
International Organization for Standardization	ISO
Kilowatt hours	kWh
Lifecycle analysis	LCA
Liquid Crystal Display	LCD
Low Temperature Polysilicon	LTPS
Microsecond	µs
Millisecond	ms
Milliwatt	mW
Minute	min
Minutes	mins
National Television System Committee	NTSC
Organic Light Emitting Diodes	OLED

Organization for Economic Co-operation and Development	OECD
Original Display Manufacturer	ODM
Original Equipment Manufacturer	OEM
Quarter Video Graphics Array	QVGA
Research and Development	R&D
Restriction of Hazardous Substances	RoHS
Return on Investment	ROI
Television	TV
Terawatt hours	TWh
Thin-Film Transistor	TFT

Section 6

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Section 8

SOURCES AND METHODOLOGY

Pike Research's industry analysts utilize a variety of research sources in preparing Research Reports. The key component of Pike Research's analysis is primary research gained from phone and in-person interviews with industry leaders, including executives, engineers, and marketing professionals. Analysts are diligent in ensuring that they speak with representatives from every part of the value chain, including but not limited to, technology companies, utilities and other service providers, industry associations, government agencies, and the investment community.

Additional analysis includes secondary research conducted by Pike Research's analysts and the firm's staff of research assistants. Where applicable, all secondary research sources are appropriately cited within this report.

These primary and secondary research sources, combined with the analyst's industry expertise, are synthesized into the qualitative and quantitative analysis presented in Pike Research's reports. Great care is taken in making sure that all analysis is well-supported by facts, but where the facts are unknown and assumptions must be made, analysts document their assumptions and are prepared to explain their methodology, both within the body of a report and in direct conversations with clients.

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