F-GHG Emissions Reduction Efforts: 2016 Supplier Profiles

U.S. Environmental Protection Agency
Office of Air and Radiation
April 2018

The Supplier Profiles outlined in this document detail the efforts of large-area flat panel suppliers to reduce their fluorinated greenhouse gas (F-GHG) emissions in manufacturing facilities that make today's large-area panels used for products such as TVs and computer monitors. More comprehensive information on how F-GHGs are used in flat panel display (FPD) manufacturing is available on the Center for Corporate Climate Leadership's website at: https://www.epa.gov/climateleadership/center-corporate-climate-leadership-sector-spotlight-electronics.

Summary of Supplier Profiles

The table below summarizes which panel suppliers publicly report their F-GHG emissions, their most recent F-GHG emissions, and, where available, their F-GHG emissions intensity based on panel production. It also includes information on suppliers' broader GHG emission reduction goals, since F-GHGs comprise a significant portion of on-site Scope 1 GHG emissions, as well as the regulatory and/or voluntary efforts by which suppliers are reducing their F-GHG emissions.

Most importantly, the table highlights which suppliers have fully implemented F-GHG emissions reduction measures across their older and newer manufacturing, or fabrication, facilities, also referred to as 'fabs.' For panel suppliers that have not fully implemented F-GHG reduction measures, whereby approximately 90 percent of annual F-GHG emissions are avoided or removed, further opportunities for improvement exist.

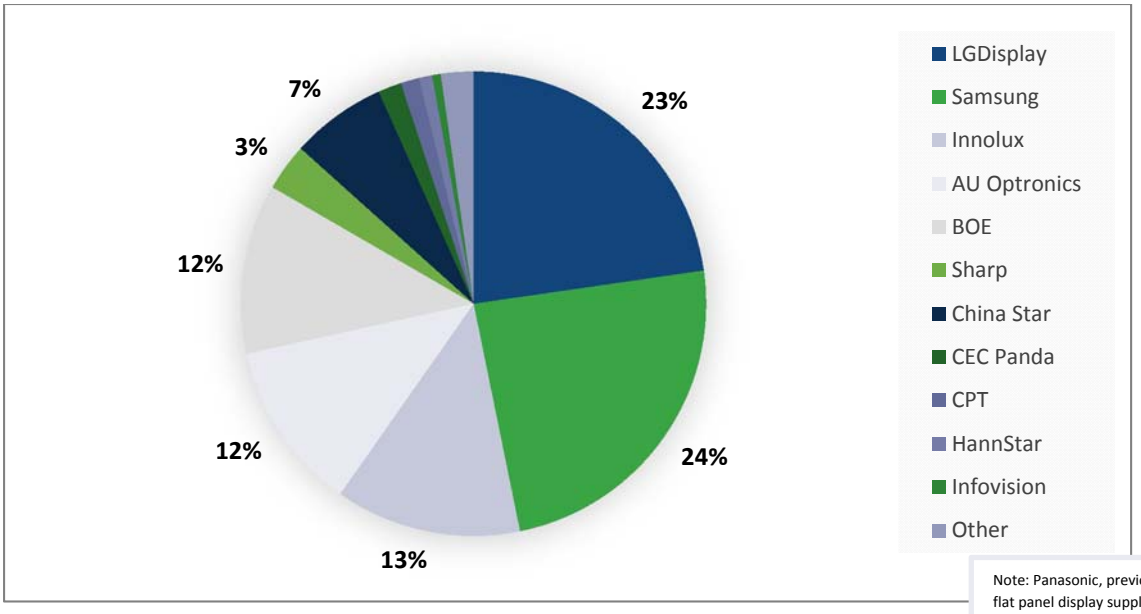
The summary table and charts below reflect data, assembled from public sources and the suppliers themselves, on F-GHG emissions for calendar year or fiscal year 2016, depending on the supplier's reporting cycle. Public sources of information include suppliers' responses to the annual CDP Investor Questionnaire and each supplier's annual sustainability reports.

Following the summary information, individual profiles provide more information on specific methods, such as abatement, process optimization and use of alternatives that suppliers are using to reduce their F-GHG emissions.

Supplier Market Share

The eleven global flat panel display suppliers named among the profiles produce 98% of all large-area flat panel displays sold globally, as shown in the chart below. Large area panels are defined as being 9.1 inches or larger.

2016 Global Market Share of Large Area Panels Production for Featured Suppliers

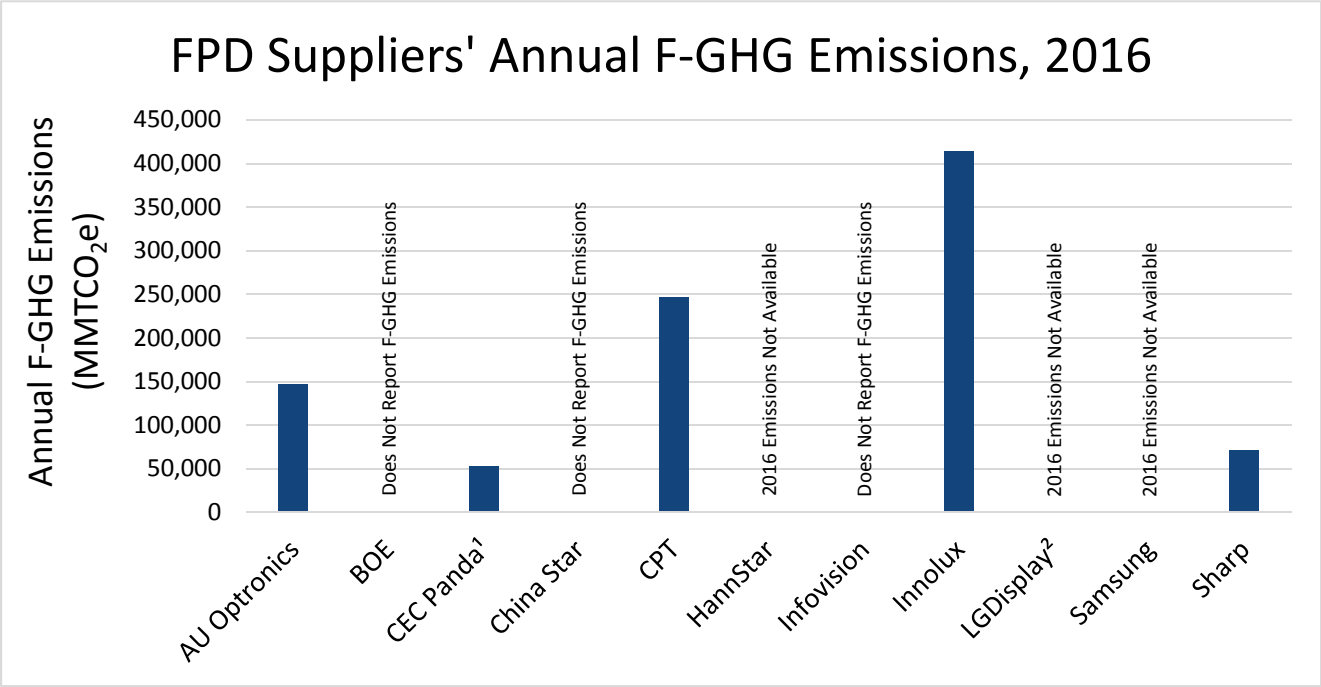


Source: IHS Technology 2016. "Large Area Display Production Strategy Tracker."

Note: Panasonic, previously listed as a global flat panel display supplier through 2015, exited its LCD panel manufacturing business in 2016.

Key Findings Based on 2016 Data

- Some suppliers who previously reported annual F-GHG emissions did not provide amounts for their 2016 calendar year reports. While some liquid crystal display (LCD) suppliers have reported, and continue to report, their F-GHG emissions publicly, others with large and/or increasing market share opt to report their F-GHG emissions either privately or directly to their customers. Thus, greater transparency is still needed on all LCD panel suppliers' F-GHG emissions to better understand overall trends in F-GHG emissions.
- An improved understanding is needed on the extent to which F-GHG emission reductions result from both the use of F-GHG reduction technologies and the use of alternative F-GHGs in key processes. This will better equip brands to understand all methods their suppliers implement to reduce F-GHG emissions.
- An optimal F-GHG emission intensity, based on full abatement and/or the fullest use of alternative gases, could serve as an indicator for brands and other interested stakeholders on whether emission reduction efforts have been implemented to the fullest extent possible.



[1] CEC Panda reported HFC emissions in 2015 but not 2016.

[2] LG Display reports on F-GHG reduction efforts, but did not report actual F-GHG emissions for 2016.

Source: Data from publicly available sources as detailed in the individual supplier profiles.

New Development: IEEE 1680.1 Standard

- In March 2018, the ***IEEE 1680.1-2018 Standard for Environmental and Social Responsibility Assessment of Computers and Displays*** was published, replacing a previous version.
- This standard includes new criteria that incentivize improvements across many different environmental impacts. One of the new optional criterion addresses F-GHG capture and destruction of F-GHG emissions by flat panel display suppliers. For a brand manufacturer (Original Equipment Manufacturer (OEM)) to declare that a product containing flat panel displays meets the F-GHG criteria and conforms to the standard, at least 75% of its flat panel display suppliers, by amount spent during the annual fiscal or calendar year, must demonstrate that they are reducing annual F-GHG emissions by 90 percent.

Application of the IEEE 1680.1 Standard

- The revised IEEE 1680.1 standard aims to foster greater sustainability in the Information Technology (IT) supply chain since the criteria of the standard underpin the Electronic Product Environmental Assessment Tool (EPEAT), a sustainability rating tool for certain electronics. An IT product receives an EPEAT Bronze, Silver, or Gold rating. Bronze-rated products meet minimum required criteria only, whereas Silver and Gold-rated products also meet additional amounts of optional criteria.

- Computer and Display products that are “EPEAT registered” will be required to meet the IEEE 1680.1 standard. A registry of conformant products will be publicly available at www.epeat.net beginning in November 2018.
- Many institutional purchasers around the globe, including the United States Federal government, purchase EPEAT- registered products. Thus, once the registry becomes available, purchasers will be able to determine more easily if EPEAT-registered products containing flat panel displays, namely monitors and laptops, meet the optional F-GHG emissions reduction criterion.

Company	Market Share of FPD Production	Publicly Reported 2016 F-GHGs	2016 F-GHG Emissions ($MMTCO_2e$)	% Reduction from 2015	2016 F-GHG Intensity ($MMTCO_2e/m^2$ of panel produced)	GHG Reduction Goals[1]	National Regulations on F-GHGs/Carbon Trading	Participation in Voluntary National/International (i.e., WDICC) F-GHG Efforts?	F-GHGs Targeted by Emission Reduction Efforts				Processes Targeted by Emission Reduction Efforts			Reduction Approach(es) Used				Full F-GHG Emission Reduction Measures Implemented at Each Fab (resulting in overall ~90% F-GHG emission reductions across all fabs)	
									SF_6	PFCs	HFCs	NF_3	Etch	Clean	Heat Transfer	Abatement	Process Improvements	CVD Remote Plasma	Other	Newer Fabs (built after 2003)	Older Fabs
LG Display	23%		Not Available	NA	Not Available	12.6% by 2020	✓	✓	✓	✓	not used	✓	✓	✓	F-GHGs not used	✓	✓	✓			
Samsung	24%		*2016 F-GHG emissions data is not publicly available, however data for 2011 and part of 2012 are available in previous profiles.*																		
Innolux	13%	✓	414,713	NA[2]	0.0066	No	✓	✓	✓	✓	✓	✓	✓	✓	not inventoried	✓	✓			✓	✓
AU Optronics	12%	✓	147,045	28%	0.043	25% by 2015	✓	✓	✓	CF_4	✓	✓	✓	✓	deemed too minor	✓	✓			✓	✓
BOE	12%		*2016 F-GHG emissions data is not publicly available, however information on general GHG emissions management efforts is publicly available.*																		
Sharp	3%	✓	72,000	15%	Not Available	No		✓	✓	CF_4 C_2F_6 C_4F_8	CHF_3	✓	✓	✓	no info available	✓	✓		✓	✓	✓
China Star	7%		*2016 F-GHG emissions data is not publicly available.*																		
CEC Panda	2%	✓	53,312	12%[3]	Not Available	10% by 2016		Unknown	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*		
CPT	1%	✓	247,112	21%	Not Available	280,000 $MtCO_2e$ by 2016		✓	✓	✓	✓	✓	✓	✓	no info available	✓	✓			✓	
HannStar	1%		Not Available	NA	Not Available	No	✓	✓	✓	✓		✓	✓	✓	F-GHGs not used	✓	✓			✓	
Infovision	1%		*2016 F-GHG emissions data is not publicly available.*																		

[1] For more information on GHG emission reduction goals, including the base year and scope of included emissions, see the individual Supplier Profiles.

[2] Innolux's F-GHG emissions increase by 5.6% compared to 2015.

[3] The percent reduction for CEC Panda does not include HFC emissions because CEC Panda did not report HFC emissions for 2016.

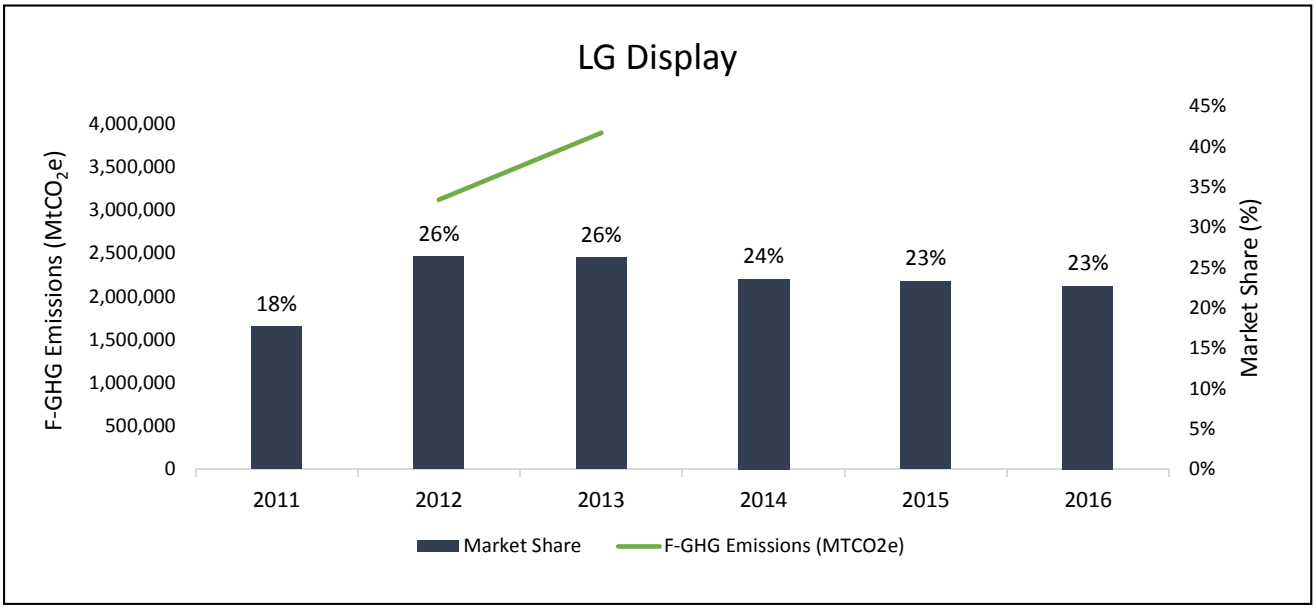
Flat Panel Display Supplier Profiles

Flat panel display suppliers are presented in descending order of market share.

LG Display 2016 Data

23% Market Share

F-GHG Emissions Over Time



The chart above shows the following separate but related metrics:

- ***Market share** over time shows the size of the supplier relative to all suppliers in the industry based on area of panels produced.*
- ***Total emissions** over time show total F-GHGs emitted by the supplier each year. Supplier emissions can change due to the implementation of emissions reduction efforts, an increase or decrease in panel production, and/or LCD technology advancements.*
- ***Emission intensity**, where available, is a measure of the amount of F-GHG emissions per unit of production. Trends in emission intensity show whether the supplier's rate of emissions is increasing or decreasing over time and can indicate whether the supplier is implementing emission reduction efforts. LG Display does not publicly report F-GHG emission intensity.*

F-GHG emissions are publicly reported by suppliers through the CDP (formerly "Carbon Disclosure Project") and/or corporate sustainability reports. In this graph, market share is calculated based on production data from IHS Technology.

F-GHG Emission Reduction Activities

Overview

- There is no publicly available information on LG Display's F-GHG emissions for the most recent calendar year, however additional information for earlier years can be found in LG Display's previous profiles.

Gases Targeted

- SF_6
- PFCs
- NF_3

Processes Targeted

- Etching
- Cleaning

Approaches Used

Abatement

- **Abatement Systems:** LG Display has installed F-GHG abatement systems on all lines of cleaning tools and on two lines of etching tools. Electrically heated point-of-use systems are installed for NF_3 in cleaning tools and combustion-type centralized systems are installed for SF_6 and PFCs in etch tools.

Process Improvements

- LG Display has applied end-point detection and revised processes to optimize the use of F-GHGs.

Alternative Chemicals

- **SF_6 Replacement:** In 2014, LG Display developed a gas application technology as an alternative to using SF_6 and has started implementing the use of the alternative.
- **Remote Plasma Source Chamber Clean:** LG Display has applied NF_3 remote plasma source chamber clean (RPSC) to all manufacturing lines. RPSC's utilization rate is 97% compared to 70% for an ordinary chamber.
- **NF_3 Replacement:** LG Display has replaced NF_3 with F_2 in chamber cleaning on one of its manufacturing lines. LG Display continues to research alternative lower GWP etching gases than SF_6 for the dry etching process.
- LG Display invested 3.8 billion Korean Won (KRW) (2016) in equipment retrofitting to reduce LCD process gas. In 2016, LG Display also upgraded equipment to replace gasses used in the production of organic light-emitting diode (OLED) and plastic organic light-emitting diode (P-OLED), which are its flagship products. In the long term, LG Display is establishing a plan to reduce emissions through the introduction of process gas reduction facilities.

Emissions Measurement Approaches and Verification

- LG Display uses national GHG emission estimation guidelines issued by the South Korean Ministry of Environment and estimates NF_3 emissions by using the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories Tier 2b guidelines.
- LG Display's GHG emissions are assured by a third party in accordance with South Korean government regulations. NF_3 emissions estimated by the 2006 IPCC Tier 2b Guidelines for National Greenhouse Gas Inventories for electronics industry emissions are not assured by a third party, but cross-checked by the World Display device Industry Cooperation Committee (WDICC) members.

Emission Reduction Goals and Progress

- LG Display set a corporate-wide GHG reduction goal to reduce its GHG emissions intensity by 29% from 2009 to 2020.
- LG Display set a target to reduce Scope 1 and Scope 2 GHG emissions 12.6% by 2020 and 54.6% by 2040, relative to 2014 levels. Scope 1 emissions include F-GHGs.
- LG Display exceeded its annual 2.1% reduction goal, instead, achieving a 4.2% reduction goal (323,176 $MtCO_2eq$) for 2016 and plans to continue efforts to reduce emissions by 2020.
- LG Display reduced GHG emissions by 20% in 2016 compared to 2015 through SF6 gas substitution and energy saving campaigns.
- LG Display's F-GHG emissions reduction efforts are part of its broader goals to reduce corporate-wide GHG emissions.
- LG Display is subject to emissions caps under the Korean Emissions Trading Scheme (K-ETS) and has been participating in GHG emissions trading since January 2015. The K-ETS is the first nationwide Cap-and-Trade program in operation in East Asia.
- In 2015, LG Display implemented its Carbon Footprint Calculator to respond to government GHG regulations and respond to customer preference for environmentally friendly products.
- LG Display is a member of the Korea Display Industry Association (KDIA), where it participates in an environmental working group that promotes information exchange on GHG emissions reduction technologies and initiatives. KDIA represents Korea's flat panel display suppliers in the World Display device Industry Cooperation Committee (WDICC).

Sources

Korea Display Industry Association. See http://www.kdia.org/new/eng/.

LG Display 2016-2017 Sustainability Report. Available at http://www.lgdisplay.com/eng/sustainability/report.

LG Display 2015-2016 Sustainability Report. Available at http://www.lgdisplay.com/eng/sustainability/report.

LG Display 2014-2015 Sustainability Report. Available at http://www.lgdisplay.com/eng/sustainability/report.

LG Display (response in 2014 regarding 2012/2013 data).

LG Display's responses to the 2011 Carbon Disclosure Project Investor Questionnaire.

LG Display's responses to the 2014 Carbon Disclosure Project Investor Questionnaire.

LG Display's responses to the 2016 Carbon Disclosure Project Investor Questionnaire.

LG Display's responses to the 2017 Carbon Disclosure Project Investor Questionnaire.

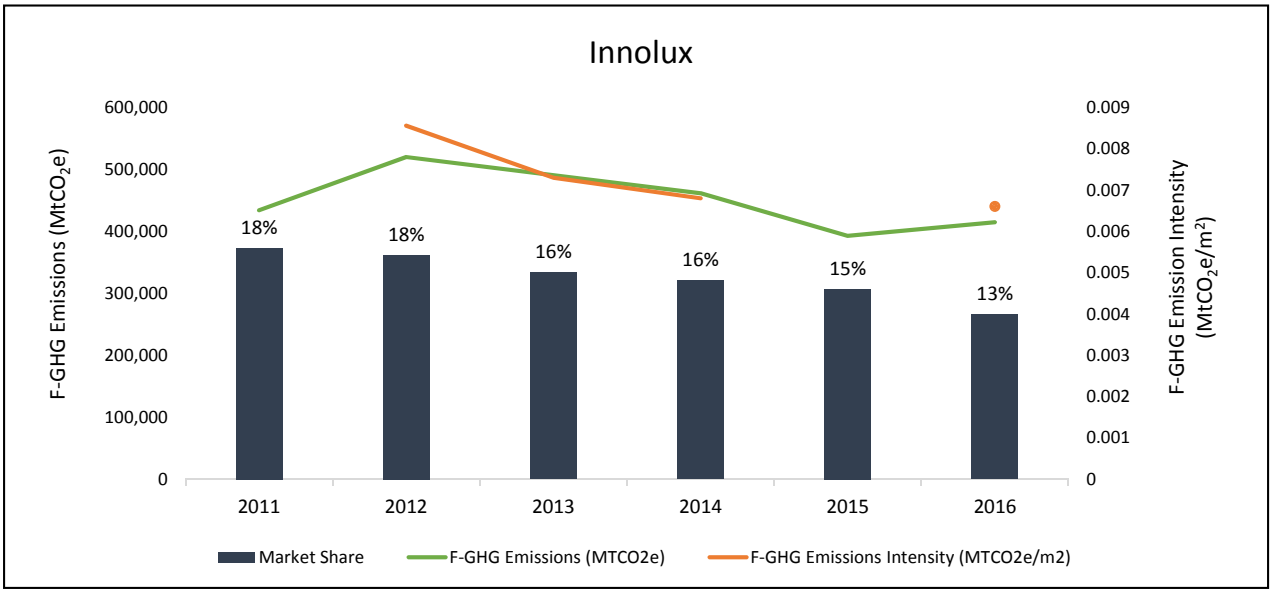
"Point of Use Abatement Device to Reduce SF6 emissions in LCD Manufacturing Operation in the Republic of Korea (South Korea)." LG Display's SF_6 Abatement Project. Clean Development Mechanism Project: 3440. Available at https://cdm.unfccc.int/Projects/DB/SGS-UKL1266943063.39/view.

"Republic of Korea: An Emissions Trading Case Study." Environmental Defense Fund, Climate Chang Research Institute of Korea, and IETA. Available at http://www.ieta.org/resources/2016%20Case%20Studies/Korean_Case_Study_2016.pdf

Innolux Corporation 2016 Data

13% Market Share

F-GHG Emissions Over Time



The chart above shows the following separate but related metrics:

- ***Market share** over time shows the size of the supplier relative to all suppliers in the industry based on area of panels produced.*
- ***Total emissions** over time show total F-GHGs emitted by the supplier each year. Supplier emissions can change due to the implementation of emissions reduction efforts, an increase or decrease in panel production, and/or LCD technology advancements.*
- ***Emission intensity**, where available, is a measure of the amount of F-GHG emissions per unit of production. Trends in emission intensity show whether the supplier's rate of emissions is increasing or decreasing over time and can indicate whether the supplier is implementing emission reduction efforts.*

F-GHG emissions are publicly reported by suppliers through the CDP (formerly "Carbon Disclosure Project") and/or corporate sustainability reports. In this graph, market share is calculated based on production data from IHS Technology.

F-GHG Emission Reduction Activities

Overview

- In 2016, Innolux emitted approximately 414,713[4] metric tons of CO_2 equivalent ($MtCO_2e$) of F-GHGs, as follows:
    - HFCs: 17,139 $MtCO_2e$
    - PFCs (includes NF_3): 27,989 $MtCO_2e$ (27,907 $MtCO_2e$ (NF3) + 82 $MtCO_2e$ (PFCs))

[4] Note that the total does not equal the sum of gases due to independent rounding.

    - SF_6: 369,584 $MtCO_2e$
- Innolux reported updated F-GHG emissions estimates for 2015 and emitted approximately 392,655 $MtCO_2e$ of F-GHGs, as follows:
    - HFC: 13,143 $MtCO_2e$
    - PFCs (includes NF3): 21,515 $MtCO_2e$ (21,303 $MtCO_2e$ (NF3) + 212 $MtCO_2e$ (PFCs))
    - SF_6: 357,997 $MtCO_2e$
- Innolux reduced its F-GHG emission intensity from 0.0094 $MtCO_2e/m^2$ of panel produced in 2010 to 0.0086 $MtCO_2e/m^2$ in 2012, and in 2013 it dropped to 0.0073 $MtCO_2e/m^2$.
- In 2014, Innolux's F-GHG emission intensity was 0.0068 $MtCO_2e/m^2$ of glass substrate. Innolux continued to achieve its goal to further reduce its F-GHG emission intensity to 0.0066 $MtCO_2e/m^2$ in 2016.
- In 2016, Innolux reported that removal equipment reduced total annual F-GHG emissions by 2,865,222 $MtCO_2e$, compared to 2,139,043 $MtCO_2e$ reduced in 2015, and 2,465,694 $MtCO_2e$ reduced in 2014.
- In 2016, F-GHGs represented 12.8 percent of Innolux's total GHG emissions compared to 12.2 percent of total emissions in 2015.[5]

Gases Targeted

- SF_6
- PFCs
- HFCs
- NF_3

Processes Targeted

- Cleaning
- Etching
- *Innolux uses a small amount of fluorinated heat transfer fluids, but has not inventoried them. In anticipation of the upcoming updates to the IPCC Guidelines, Innolux is documenting the amount of heat transfer fluids purchased in 2015 and 2016.*

Approaches Used

Abatement

- Innolux has installed burn type point-of-use abatement systems in all newer generation fabrication facilities (fabs) and installed combustion local scrubbers between 2011 and 2015, collectively eliminating 1,200 million tons of F-GHGs.
- In 2016, Innolux installed three local scrubbers in their Taiwan site, removing 2,865,222 tons of F-GHG emissions in 2016.

Process Improvements

- Innolux is optimizing the use of F-GHGs in the process chambers. Additional details not available.

[5] In 2016, Innolux's total Scope 1 emissions accounted for 14.1 percent of their total emissions, meaning F-GHG emissions make up the majority of Innolux's Scope 1 emissions.

Gas Recycling/Reuse

- **Recovery System:** Innolux is working with the Industrial Technology Research Institute of Taiwan to test an SF_6 liquefaction recovery system. If it works, Innolux will expand the system across applicable fabs.

Alternative Chemicals

- **SF_6 Replacement:** Innolux has planned to replace SF6 with NF3 in the etching process in some of its factories.
- Innolux is using lower GWP gases, where possible.

Emissions Measurement Approaches and Verification

- Innolux estimates F-GHG emissions based on the Tier 2b method for electronics industry emissions provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.
- Innolux received third party verification for its GHG inventory every year until 2016, which was verified in accordance with the ISO-14064-3 standard.
- Innolux has collected data for 12 years and passed the third party verification according to ISO 14064-1.

Emission Reduction Goals and Progress

- In 2013, Innolux released its Product Carbon Footprint (PCF) system to help streamline calculations of emissions on a per product basis.
- In 2016, Innolux audited the carbon emissions of 72 suppliers, who inventoried their GHG emissions.
- Innolux plans to continue monitoring carbon emissions to establish a comprehensive database.
- Innolux applied for early carbon credits for its carbon reduction efforts between 2005 and 2011, receiving 16 million tons in credits in 2015 for Taiwan's cap and trade program.

Participation in Broader F-GHG Reduction Efforts

- Innolux is a member of Taiwan's TFT-LCD Association (TTLA). The TTLA participates on behalf of Taiwan's LCD suppliers in the World Display device Industry Cooperation (WDICC), whose members have agreed to 30% F-GHG emission reductions by 2020 relative to 2010 levels.

Sources

2014 Innolux CSR Report. Available at http://www.Innolux.com/Files/CWSFiles/csr/2014_Innolux%20CSR%20report-en.pdf (see page 53).

2015 INNOLUX CSR Report. Available at http://www.innolux.com/Files/CWSFiles/csr/CSR2015-en_0630f.pdf (see page 47).

2016 INNOLUX CSR Report. Available at http://www.innolux.com/Files/CWSFiles/csr/CSR2016-en_0626-web.pdf.

SF_6 Abatement Strategy in Taiwan". Presentation by Taiwan's Industrial Technology Research Institute (ITRI), 2004. Available at www.epa.gov/electricpower-sf6/documents/conf04_lu.pdf.

Innolux Corporate Social Responsibility 2015 Summary. Available at *http://www.innolux.com/Pages/EN/CSR/LOVE/Green_Operations/Climate_Change_Risks_and_Opportunities_EN.html*

Innolux's responses to the 2014 Carbon Disclosure Project Investor Questionnaire.

Innolux's responses to the 2015 Carbon Disclosure Project Investor Questionnaire.

Innolux's responses to the 2016 Carbon Disclosure Project Investor Questionnaire.

Innolux's responses to the 2017 Carbon Disclosure Project Investor Questionnaire.

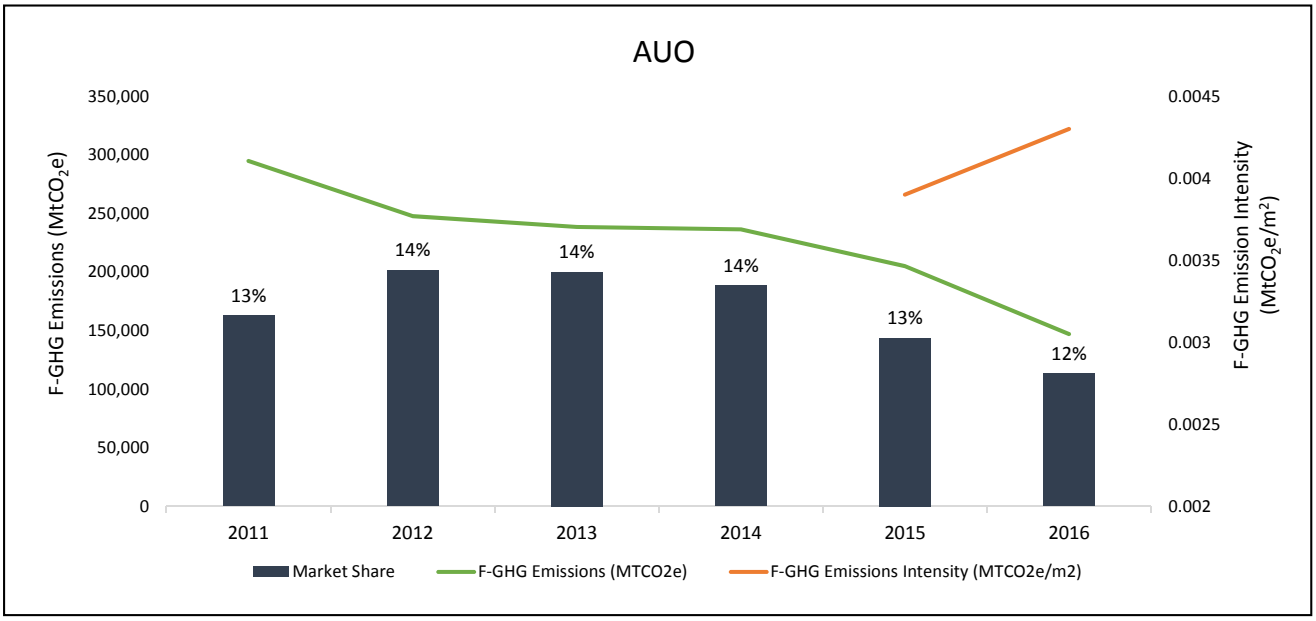
Taiwan Environmental Protection Administration. "The Initiative and Efforts from Electronic Corporations in Taiwan- Semiconductor and TFT-LCD." Available at *http://unfccc.epa.gov.tw/unfccc/english/_uploads/downloads/05_The_Initiative_and_Efforts_form_Electronic_Industry_in_Taiwan.pdf.*

TTLA presentation at APEC meeting, August 2012, Taiwan.

AUO (AU Optronics) 2016 Data

12% Market Share

F-GHG Emissions Over Time



The chart above shows the following separate but related metrics:

- ***Market share** over time shows the size of the supplier relative to all suppliers in the industry based on area of panels produced.*
- ***Total emissions** over time show total F-GHGs emitted by the supplier each year. Supplier emissions can change due to the implementation of emissions reduction efforts, an increase or decrease in panel production, and/or LCD technology advancements.*
- ***Emission intensity**, where available, is a measure of the amount of F-GHG emissions per unit of production. Trends in emission intensity show whether the supplier's rate of emissions is increasing or decreasing over time and can indicate whether the supplier is implementing emission reduction efforts.*

F-GHG emissions are publicly reported by suppliers through the CDP (formerly "Carbon Disclosure Project") and/or corporate sustainability reports. In this graph, market share is calculated based on production data from IHS Technology.

F-GHG Emission Reduction Activities

Overview

- In 2016, AUO emitted approximately 147,000 metric tons of CO_2 equivalent ($MtCO_2e$) of F-GHGs, as follows:
  - HFCs: 6,821.5 $MtCO_2e$
  - PFCs (includes NF_3): 22,330.4 $MtCO_2e$ (19503.3 $MtCO_2e$ (NF3) + 2827.1 $MtCO_2e$ (PFCs))
  - SF_6: 117,892.7 $MtCO_2e$

- From 2010 to 2016, AUO reduced its GHG emissions intensity, which includes both Scope 1 and Scope 2 GHG emissions, by 20%, from 58.5 kg CO_2e/m^2 (0.059 $MtCO_2e/m^2$) of panel produced to 49.0 kg CO_2e/m^2 (0.049 $MtCO_2e/m^2$). AUO has pledged to continue its efforts to achieve an additional 5% reduction in emissions intensity by 2020 to attain their 25% GHG reduction goal. Specifically, from 2008 to 2016, AUO reported a 58% reduction in F-GHG emissions per unit of production, from 9.96 kg CO_2e/m^2 (0.010 $MtCO_2e/m^2$) to 4.31 kg CO_2e/m^2 (0.0043 $MtCO_2e/m^2$).
- AUO's direct Scope 1 GHG emission intensity was 4.3 $kgCO_2e/m2$, a 27% reduction compared to that of 2015. The corresponding indirect GHG emissions intensity for Scope 2 was 45 $kgCO_2e/m2$, a 4.5% reduction compared to 2015.
- From 2003 to 2016, AUO reduced F-GHG emissions by 12.1 million metric tons CO_2e. This is equivalent to taking 2.6 million cars off the road for one year.[6]

Gases Targeted

- SF_6
- PFCs (specifically CF_4)
- HFCs
- NF_3

Processes Targeted

- Etching
- Cleaning
- Cooling: *Per the "Guidance for Greenhouse Gas Accounting and Reporting for GHG inventory" published by the Taiwanese EPA, emissions from fluorinated heat transfer fluids are too minor in AUO's process to account for.*

Approaches Used

Abatement

- **Localized Abatement Systems:** As of 2015, AUO has installed localized, point-of-use abatement systems in all fabrication facilities (fabs).
- **Abatement for Cleaning:** AUO uses combustion abatement systems for cleaning processes in all fabs.
- **Abatement for Etching:** AUO uses combustion abatement systems or membrane separation technology for dry etching processes on all new production lines (built after 2003).

Process Improvements

- **Reduced SF_6 Consumption:** AUO's process experts worked with its SF_6 supplier to implement ways to reduce the quantity of SF_6 used in etching across all fabs. At one of its fabs, at full production capacity,

[6] Calculated using *EPA's Greenhouse Gas Equivalencies Calculator, which is available at* *https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator*

adjusting relevant SF_6 process parameters can result in reducing the equivalent of 32,000 metric tons of CO_2 annually, which is equal to 18% of AUO's reported SF_6 emissions in 2015.

- **Reduced Gas Waste and Improved Utilization Efficiencies:** By installing flow meters and mass flow controllers at the front of tool chambers, on-site engineers have been able to reduce unnecessary gas waste and improve gas utilization efficiencies.
- **Process Changes and Enhancements:** In 2016, the Green Production Team under the Green Manufacturing Subcommittee implemented 449 projects including installing energy-saving chillers/pumps, introducing wireless smart meters and enhancing the efficiency of the PFC abatement systems. 62% of the emissions reduction was achieved through refined procedures and enhanced management, whereas 38% was achieved through investments.

Alternative Chemicals

- **NF_3 Substitution:** AUO uses NF_3 instead of SF_6 in cleaning, since NF_3 has a lower global warming potential (GWP) and it is used more efficiently.
- **Ongoing Research:** AUO continues to research the possibilities of using alternative gases with lower or no GWP in conjunction with optimizing process efficiencies and implementing abatement systems.

Gas Recycling/Reuse

- **Recycling Test:** In 2012, AUO tested gas recycling technologies and recycling efficiency at one fab.
- **Reuse Pilot:** In 2013, AUO's Longtan site introduced a membrane separation method that purifies SF_6 so that it can be re-used in the manufacturing process. However, due to a higher maintenance demand and lower efficiency, the recycling system has been replaced by an abatement system.

Emissions Measurement Approaches and Verification

- AUO estimates F-GHG emissions based on the Tier 2b method for electronics industry emissions provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, including use of default destruction or removal efficiency (DRE) values for abatement.
- A third party verifies AUO's raw data according to the ISO 14064-1 guidance (verification document included below).
- Fluorinated compounds emissions in 2016 with and without abatement equipment were calculated as 140,224.02 and 1,561,500.27 $MtCO_2e$, respectively, which indicates a reduction of 1,421,276.66 $MtCO_2e$. This emissions reduction activity was third-party verified and conducted in accordance with ISO 14064-3:2006.

Emission Reduction Goals and Progress

- AUO set a goal to reduce Scope 1 and 2 GHG emission intensity in all fabs globally by 25% from 2010 to 2015. F-GHGs are included as part of Scope 1 emissions.
- AUO set a subsequent goal for all manufacturing sites in Taiwan to reduce Scope 1 and 2 GHG emission intensity per square meter of glass produced by 5% by 2020 compared to 2015.
- AUO has a "Green Solutions" initiative that addresses emissions reductions through operations, supply chain improvements, and product design.

- AUO announced its “Carbon 2020” strategy in 2015, which aims to reduce carbon emissions to 1 million tons by 2020 and implement strategies in all areas from the optimization of product design, material usage, manufacturing processes and logistic options to the provision of energy-efficient solutions to customers.
- By setting 2005 as the base year, AUO expects to achieve a 20% GHG reduction by the end of 2030 with an additional 30% reduction before 2050 to cut emission levels in half that compared to 2005.

Participation in Broader F-GHG Reduction Efforts

- AUO is a member of Taiwan’s TFT-LCD Association (TTLA). The TTLA participates on behalf of Taiwan’s LCD suppliers in the World Display device Industry Cooperation (WDICC), whose members have agreed to 30% F-GHG emission reductions by 2020 relative to 2010 levels.
- AUO participates in the Product Attribute to Impact Algorithm (PAIA) Project to develop lifecycle impact calculation tools for LCDs, capturing F-GHG emissions information. AUO has employed a methodology to manufacture low-carbon LCD products, including 15.6" notebook panels, 65" and 55" curve panels, and 18.5" to 24" desktop monitors.
- AUO has engaged in developing the SF_6 abatement verification methodology for LCD industries in Taiwan.
- AUO received 9.41 million tons of tradeable carbon credits by the Taiwan EPA for its early action on PFC reductions and third party verification of its F-GHG abatement. In 2016, AUO signed the largest carbon credit trading deal in Taiwan. A total of 5 million tons were traded through the Taiwan EPA’s domestic carbon trading platform.

DNV·GL

VERIFICATION STATEMENT OF GREENHOUSE GAS ASSERTIONS

Statement No.:
00003-2017-AG-TWN

Issued date:
12 May, 2017

This is to verify initiate reporting of Greenhouse Gas Inventory Management Report (2016) of

AU Optronics Corporation

Scope of Verification
DNV GL Business Assurance (DNV GL) has been commissioned by AU Optronics Corporation to perform a verification of the greenhouse gas assertion of Greenhouse Gas Inventory Management Report (2016) (hereafter the "Inventory Report") with respect to the sites listed in Appendix.

Verification Criteria and GHG Programme
The verification was performed on the basis of ISO 14064-1:2006 and CNS 14064-1:2006 as well as criteria given to provide for consistent GHG emission identification, calculation, monitoring and reporting. The verification was conducted in accordance with ISO 14064-3: 2006.

Verification Statement
It is DNV GL's opinion that with reasonable assurance the greenhouse gas assertion of the Inventory Report of April 20, 2017 is free from material discrepancies in accordance with ISO 14064-1:2006 and CNS 14064-1:2006. DNV GL thus requests the registration of the Inventory Report as a GHG inventory demonstration project.

Sophia Kim
GHG Verifier

Place and date:
Taipei, 12 May, 2017

For the issuing office:
DNV GL Business Assurance Co., Ltd.
29Fl., No. 293, Sec. 2, Wenhua Rd., Banqiao District, New Taipei City 220, Taiwan

Management Representative

Sources

AUO 2011 Corporate Social Responsibility Report.

AUO 2013 Corporate Social Responsibility Report (Section 4.2.1, page 61) Available at http://www.auo.com/upload/download/1/AUO_2013_CSR_EN_All.pdf.

AUO 2015 Corporate Social Responsibility Report (Section 4.2.1, page 82). Available at http://www.auo.com/upload/download/1/2015_CSR_All_en.pdf.

AUO 2016 Corporate Social Responsibility Report. Available at https://www.auo.com/ja-JP/Report_and_Certificate/download/1166

AUO's responses to the 2014 Carbon Disclosure Project Investor Questionnaire.

AUO's responses to the 2015 Carbon Disclosure Project Investor Questionnaire.

AUO's responses to the 2016 Carbon Disclosure Project Investor Questionnaire.

AUO's responses to the 2017 Carbon Disclosure Project Investor Questionnaire.

AUO direct communications.

EPA Greenhouse Gas Equivalencies Calculator. Available at https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator.

Taiwan Environmental Protection Administration. "The Initiative and Efforts from Electronic Corporations in Taiwan- Semiconductor and TFT-LCD." Available at http://unfccc.epa.gov.tw/unfccc/english/_uploads/downloads/05_The_Initiative_and_Efforts_form_Electronic_Industry_in_Taiwan.pdf.

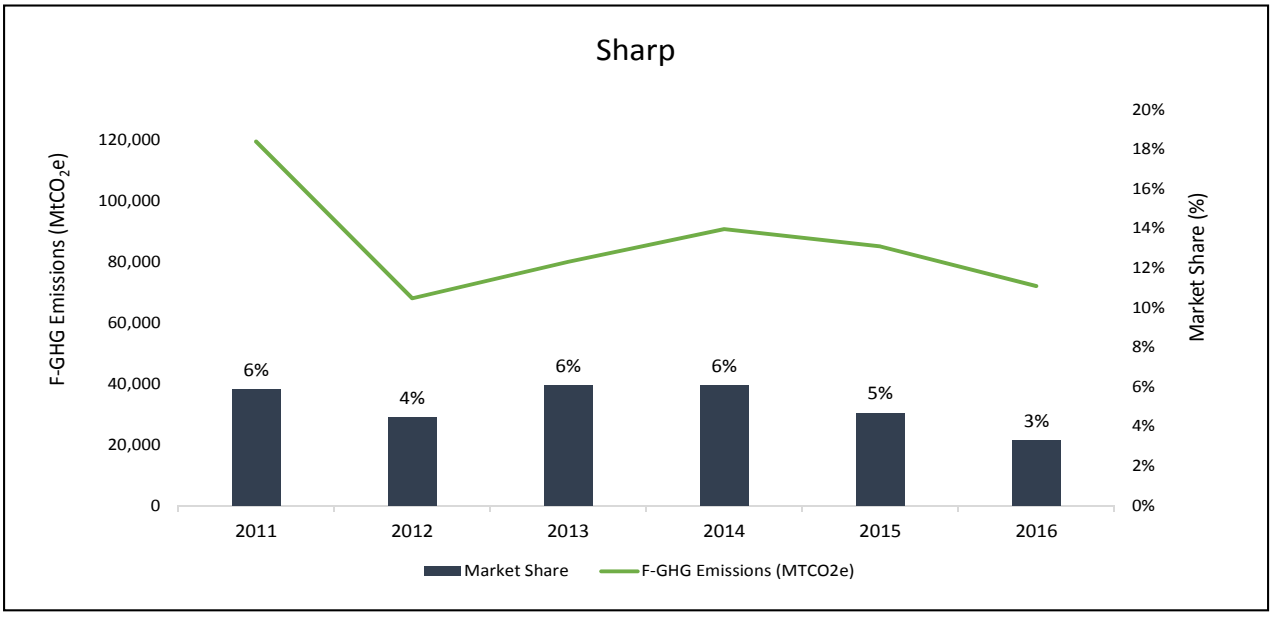
TTLA presentation at APEC meeting, August 2012, Taiwan.

World Display device Industry Cooperation Committee Environmental Report. Available at http://home.jeita.or.jp/device/committee/pdf/Environmental%20Report_ENG_161110.pdf.

Sharp 2016 Data

3% Market Share

Emissions Over Time



The chart above shows the following separate but related metrics:

- ***Market share** over time shows the size of the supplier relative to all suppliers in the industry based on area of panels produced.*
- ***Total emissions** over time show total F-GHGs emitted by the supplier each year. Supplier emissions can change due to the implementation of emissions reduction efforts, an increase or decrease in panel production, and/or LCD technology advancements.*
- ***Emission intensity**, where available, is a measure of the amount of F-GHG emissions per unit of production. Trends in emission intensity show whether the supplier's rate of emissions is increasing or decreasing over time and can indicate whether the supplier is implementing emission reduction efforts. Sharp does not publicly report F-GHG emission intensity.*

F-GHG emissions are publicly reported by suppliers through the CDP (formerly "Carbon Disclosure Project") and/or corporate sustainability reports. In this graph market share is calculated based on production data from IHS Technology.

F-GHG Emissions Reduction Activities

Overview

- In 2016, Sharp emitted a total of approximately 72,000 metric tons of CO_2 equivalent ($MtCO_2e$) of F-GHGs, as follows:[7]

[7] Sharp reports annual emissions for its fiscal year, April 1 through March 31, rather than calendar year.

- HFCs: 3,000 $MtCO_2e$
- PFCs: 31,000 $MtCO_2e$
- SF_6: 30,000 $MtCO_2e$
- NF_3: 8,000 $MtCO_2e$

Gases Targeted

- SF_6
- PFCs (CF_4, C_2F_6, C_4F_8)
- HFCs (CHF_3)
- NF_3

Processes Targeted

- Etching
- Cleaning

Approaches Used

Abatement

- **Abatement Systems:** Sharp has installed abatement systems on all etching and cleaning process equipment.
- **Scrubbers and Exhaust Treatment:** Sharp has installed scrubbers and exhaust gas treatment systems.

Process Improvements

- **Researching Process Optimization:** Sharp has been researching ways to improve process optimization and manufacturing process conditions at the time that manufacturing equipment is first installed and in daily operations.

Alternative Chemicals

- **Researching Lower GWP Gases:** Sharp has been collecting the latest information from relevant sources and researching the possibility of using lower GWP alternative gases.

Gas Recycling/Reuse

Not applicable.

Emissions Measurement Approaches and Verification

- Sharp estimates F-GHG emissions based on the Tier 2b method for electronics industry emissions provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.
- Sharp's reported Scope 1 emissions, which include F-GHGs, have not undergone third party verification.

Emission Reduction Goals and Progress

- Sharp works to reduce F-GHG emissions in accordance with the targets of Ministry of Economy, Trade and Industry; the Japan Electronics and Information Technology Industries Association (JEITA); and other industrial associations.

- Sharp set a goal to reduce annual GHG emissions to below 2007 baseline emissions levels for ten manufacturing fabrication facilities (fabs) by 2011.
- Sharp set a goal to reduce GHG emissions intensity per adjusted production unit (tons of CO_2e/100 million yen) by 35% across the ten fabs by 2012. By end of fiscal year 2011, Sharp met both of its goals and reduced total emissions by 40% and emissions intensity by 42%.
- In fiscal year 2016, the Sharp Group's GHG emissions decreased by 8.9% compared to the previous fiscal year. Sharp's F-GHG emissions decreased from 93,000 tons of CO_2e in fiscal year 2015 to 73,000 tons of CO_2e in fiscal year 2016.

Participation in Broader F-GHG Reduction Efforts

- Sharp is a member of the Japan Electronics and Information Technology Industries Association (JEITA), which participates on behalf of Japan's LCD suppliers in the World Display device Industry Cooperation Committee (WDICC).

Sources

Japan Electronics and Information Technology Industries Association (JEITA). See http://www.jeita.or.jp/english/.

Nishida, et al. PFC Emission Reduction Strategy for the LCD Industry. Journal of the SID 13/10. 2005

Sharp (Sharp Corporation).

Sharp Corporation's responses to the 2017 Carbon Disclosure Project Investor Questionnaire.

Sustainability Report 2016 by the Sharp Corporation, page 21. Available at: http://www.sharp-world.com/corporate/eco/report/ssr/pdf/ssr2016e.pdf.

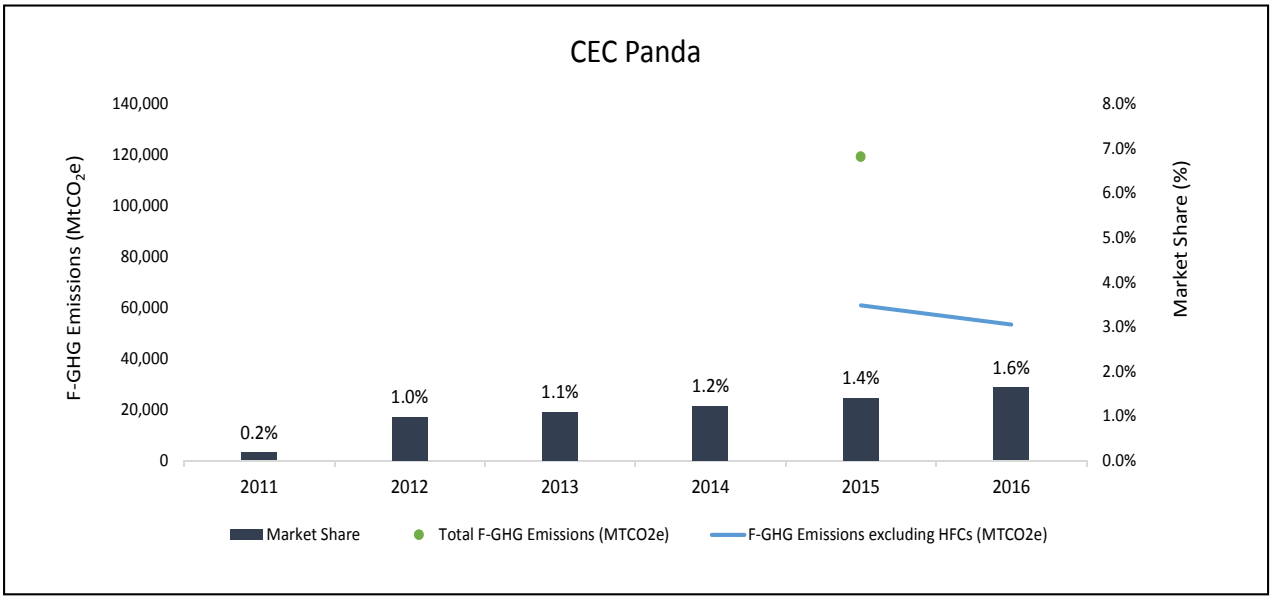
Sustainability Report 2016 by the Sharp Corporation. Available at: http://www.sharp.co.jp/corporate/eco/report/ssr/index.html.

Sustainability Report 2017 by the Sharp Corporation. Available at: http://www.sharp-world.com/corporate/eco/report/ssr/pdf/ssr2017e.pdf

CEC Panda 2016 Data

2% Market Share

Emissions Over Time



The chart above shows the following separate but related metrics:

- ***Market share** over time shows the size of the supplier relative to all suppliers in the industry based on area of panels produced.*
- ***Total emissions** over time show total F-GHGs emitted by the supplier each year. Supplier emissions can change due to the implementation of emissions reduction efforts, an increase or decrease in panel production, and/or LCD technology advancements.*
- ***Emission intensity**, where available, is a measure of the amount of F-GHG emissions per unit of production. Trends in emission intensity show whether the supplier's rate of emissions is increasing or decreasing over time and can indicate whether the supplier is implementing emission reduction efforts. CEC Panda does not publicly report F-GHG emission intensity. Note that CEC Panda reported HFC emissions in 2015, but not in 2016, so the chart above shows F-GHG emissions both including and excluding HFC emissions for comparison between years.*

F-GHG emissions are publicly reported by suppliers through the CDP (formerly "Carbon Disclosure Project") and/or corporate sustainability reports. In this graph, market share is calculated based on production data from IHS Technology.

F-GHG Emission Reduction Activities

Overview

- In 2016, per its second year of reporting F-GHG emissions to the CDP, CEC Panda emitted a total of approximately 53,312 metric tons of CO_2 equivalent ($MtCO_2e$) of F-GHGs, as follows:[8]
    - PFCs: 2,297 $MtCO_2e$
    - SF_6: 11,082 $MtCO_2e$
    - NF_3: 39,933 $MtCO_2e$

Gases Targeted

No information is available on gases targeted by CEC Panda's F-GHG emission reduction activities.

Processes Targeted

No information is available on processes targeted by CEC Panda's F-GHG emission reduction activities.

Approaches Used

No information is available on approaches used by CEC Panda to reduce F-GHG emissions.

Emissions Measurement Approaches and Verification

- CEC PANDA estimates its F-GHG emissions based on the Tier 2b method provided by the 2006 IPCC Guidelines for National Greenhouse Gas Inventories for electronics industry emissions.
- CEC PANDA has not undergone third party verification or assurance for its reported Scope 1 emissions, which include F-GHG emissions, for its calendar year 2015 GHG inventory data.

Emission Reduction Goals and Progress

- CEC Panda set a goal to reduce Scope 2 GHG emissions by 10% from 2015 to 2016 and reported that 100% of the target was achieved in 2016.
- In 2016, CEC Panda implemented 37 projects to reduce GHG emissions by an estimated annual 7301 CO_2e savings in metric tons CO_2e.

Participation in Broader F-GHG Reduction Efforts

No information is available on CEC Panda's participation in broader F-GHG reduction efforts.

Sources

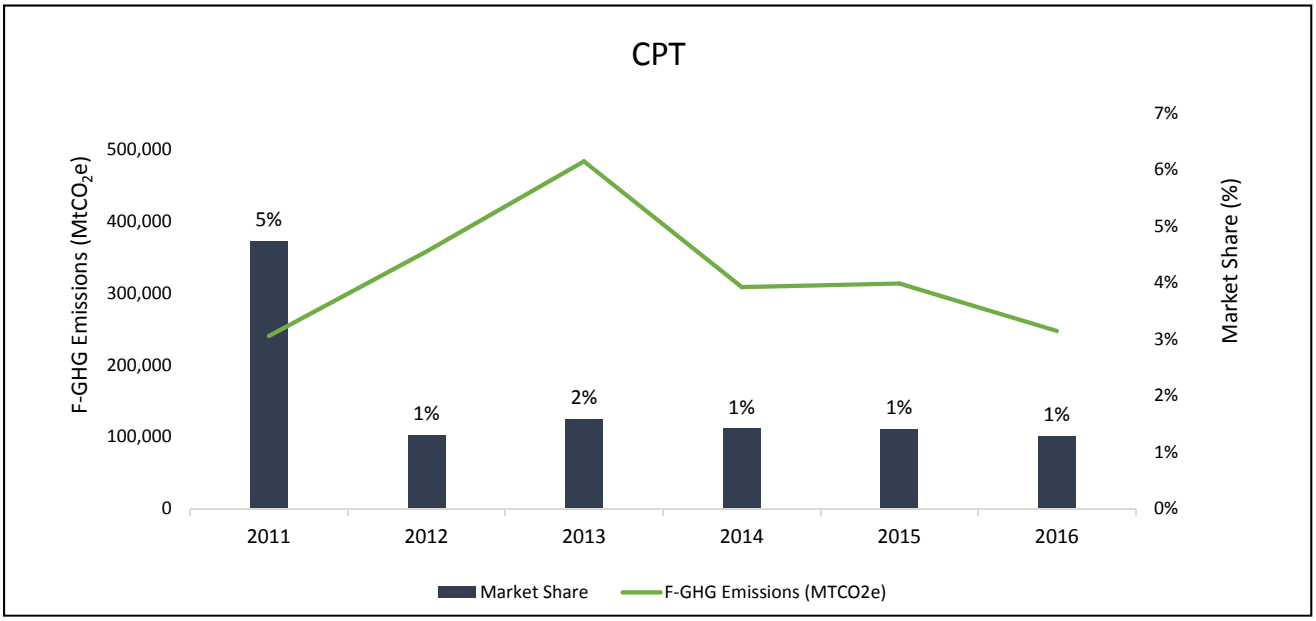
CEC PANDA's responses to the 2016 CDP Investor Questionnaire
CEC PANDA's responses to the 2017 CDP Investor Questionnaire

[8] CEC Panda reported HFC emissions in 2015 but not 2016.

Chunghwa Picture Tubes (CPT) 2016 Data

1% Market Share

F-GHG Emissions Over Time



The chart above shows the following separate but related metrics:

- ***Market share** over time shows the size of the supplier relative to all suppliers in the industry based on area of panels produced.*
- ***Total emissions** over time show total F-GHGs emitted by the supplier each year. Supplier emissions can change due to the implementation of emissions reduction efforts, an increase or decrease in panel production, and/or LCD technology advancements.*
- ***Emission intensity**, where available, is a measure of the amount of F-GHG emissions per unit of production. Trends in emission intensity show whether the supplier's rate of emissions is increasing or decreasing over time and can indicate whether the supplier is implementing emission reduction efforts. CPT does not publicly report F-GHG emission intensity.*

F-GHG emissions are publicly reported by suppliers through the CDP (formerly "Carbon Disclosure Project") and/or corporate sustainability reports. In this graph, market share is calculated based on production data from IHS Technology.

F-GHG Emission Reduction Activities

Overview

- In 2016, CPT emitted approximately 247,112 metric tons of CO_2 equivalent ($MtCO_2e$) of F-GHGs, a 55% reduction from 2008, compared to a 49% reduction from 2008 in 2015 (313,000 $MtCO_2e$).

- CPT reduced F-GHG emissions by approximately 34.53 million $MtCO_2e$ between 2002 and 2016. This is equivalent to removing 7.4 million vehicles from the road for one year.[9]
- In 2016, PFC emissions accounted for nearly 32% of all emissions.

Gases Targeted

- SF_6
- PFCs
- HFCs
- NF_3

Processes Targeted

- Etching
- Cleaning

Approaches Used

Abatement

- **Abatement Systems:** CPT has installed abatement systems in all newer generation fabrication facilities (fabs).

Process Improvements

- **PFC Reduction:** In 2014, CPT implemented PFC reduction methods and evaluated process equipment, targeting its 4.5 generation fabs, an earlier generation of fabs built prior to 2004. CPT conforms to the WDICC resolution set in 2003 requiring that new plants install F-GHGs treatment facilities.
- **Cleaning Process:** CPT completed reconstruction of the cleaning process in their Taoyuan and Longtan plants, resulting in a 38% emission reduction of fluorinated compounds in 2011 from 2010 levels, equal to approximately 170,000 $MtCO_2e$.

Alternative Chemicals

- **SF_6 Replacement:** CPT is using lower GWP gases, where possible. For example, CPT continues to implement carbon reduction activities by replacing SF_6 with NF_3 in cleaning processes.

Emissions Measurement Approaches and Verification

- CPT estimates its F-GHG emissions based on the Tier 2b method provided by the 2006 IPCC Guidelines for National Greenhouse Gas Inventories for electronics industry emissions.
- CPT's annual GHG inventory undergoes third party verification (verification document included below).[10]
- CPT details their GHG emission reporting requirements under the Regulations Governing GHG Emission Reporting in their Corporate Social Responsibility Report.

[9] Calculated using *EPA's Greenhouse Gas Equivalencies Calculator, which is available at https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator*

[10] CPT released its verification statement publicly in 2016 with its public disclosure.

Emission Reduction Goals and Progress

- CPT set a goal to reduce GHG emissions by 280,000 $MtCO_2e$ from 2013 to 2016 through process optimization, adoption of dry etch machinery, and installation of tail gas incinerator facilities.
- In 2016, CPT's GHG emissions were 778,618 $MtCO_2e$. The majority of CPT's GHG emissions are from F-GHG process emissions and electricity use.[11]

Participation in Broader F-GHG Reduction Efforts

- CPT is a member of the Taiwan's TFT-LCD Association (TTLA). The TTLA participates on behalf of Taiwan's LCD suppliers in the World Display device Industry Cooperation (WDICC), whose members have agreed to 30% F-GHG emission reductions by 2020 relative to 2010 levels. CPT will work with TTLA to provide regular emission information of fluorinated compounds, and engage in reductions of fluorinated compounds.

Sources

CPT 2014 Corporate Sustainability Report (page 28)
http://www.cptt.com.tw/cptt/english/html/2014_ebook_CSR_EN/index.html#p=32.

CPT 2015 Corporate Sustainability Report (page 42)
http://www.cptt.com.tw/cptt/english/html/2015_ebook_CSR_EN/index.html#p=42.

CPT 2016 Corporate Sustainability Report (page 36)
http://www.cptt.com.tw/cptt/english/html/2016_ebook_CSR_EN/mobile/index.html#p=38

CPT direct communications.

CPT's responses to the 2009 Carbon Disclosure Project Supply Chain Questionnaire.

CPT's Responses to the 2015 CDP Investor Questionnaire. Available at
https://www.cdp.net/sites/2015/45/22645/Climate%20Change%202015/Pages/DisclosureView.aspx.

CPT Website : http://www.cptt.com.tw/cptt/english/images/stories/08_CSR/CSR_07/GHG.pdf.

CPT Website: Environmental Management:
www.cptt.com.tw/index.php?option=com_content&task=view&id=447&Itemid=180.

EPA's Greenhouse Gas Equivalencies Calculator. Available at https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator.

"SF_6 Abatement Strategy in Taiwan". Presentation by Taiwan's Industrial Technology Research Institute (ITRI), 2004. Available at www.epa.gov/electricpower-sf6/documents/conf04_lu.pdf.

TTLA presentation at APEC meeting, August 2012, Taiwan.

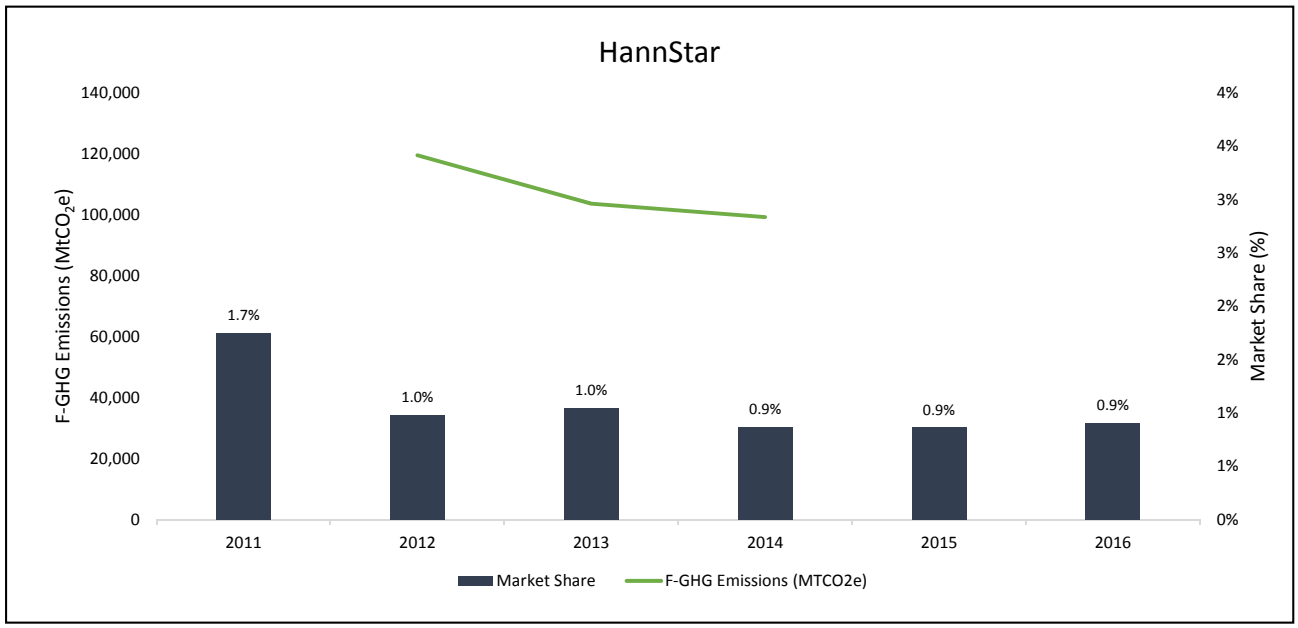
World Display device Industry Cooperation Committee Environmental Report. Available at http://home.jeita.or.jp/device/committee/pdf/Environmental%20Report_ENG_161110.pdf.

[11] GHG emission amounts listed in CPT's 2016 CSR Report were incorrect due to the fact that Taipower had not yet released its electricity coefficient at the time of report publication and PFC value links were faulty. These mistakes were corrected in the 2017 report.

HannStar 2016 Data

1% Market Share

F-GHG Emissions Over Time



The chart above shows the following separate but related metrics:

- ***Market share** over time shows the size of the supplier relative to all suppliers in the industry based on area of panels produced.*
- ***Total emissions** over time show total F-GHGs emitted by the supplier each year. Supplier emissions can change due to the implementation of emissions reduction efforts, an increase or decrease in panel production, and/or LCD technology advancements.*
- ***Emission intensity**, where available, is a measure of the amount of F-GHG emissions per unit of production. Trends in emission intensity show whether the supplier's rate of emissions is increasing or decreasing over time and can indicate whether the supplier is implementing emission reduction efforts. HannStar does not publicly report F-GHG emissions but does report total GHG emission intensity, as noted in the section below.*

F-GHG emissions are publicly reported by suppliers through the CDP (formerly "Carbon Disclosure Project") and/or corporate sustainability reports. In this graph, market share is calculated based on production data from IHS Technology.

F-GHG Emission Reduction Activities

Overview

- HannStar reduced approximately 1.55 million metric tons of CO_2 equivalent ($MtCO_2e$) of F-GHG emissions from 2007-2015.

- HannStar's total GHG emission intensity from flat panel manufacturing processes remained mostly unchanged from 0.070 $MtCO_2e/m^2$ of panel produced in 2015 to 0.072 $MtCO_2e/m^2$ in 2016.
- Overall emissions reduced by 10.5% in 2016 compared with 2015 due to consolidation of plants.

Gases Targeted

- SF_6
- NF_3

Processes Targeted

- Etching
- Cleaning

Approaches Used

Abatement

- **Local Scrubber:** HannStar has installed a high efficiency local scrubber to reduce emissions of SF_6, NF_3 and other PFCs.
- **Abatement Systems:** HannStar has installed abatement systems in all newer generation fabrication facilities (fabs).

Process Improvements

- Hannstar is optimizing the use of F-GHGs in the process chambers. Additional details not available.

Alternative Chemicals

- HannStar is using lower GWP gases, where possible. Additional details not available.

Emissions Measurement Approaches and Verification

- HannStar estimates F-GHG emissions based on the Tier 2b method for electronics industry emissions provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.
- HannStar's plants in Taiwan have been developing GHG inventories and implementing third party verification with reference to ISO 14064-1 since 2005.
- HannStar's plants in China have been developing GHG inventories since 2012, but have not had these inventories verified by a third party.

Emission Reduction Goals and Progress

- Since HannStar's GHG emissions are mostly due to electricity consumption and the use of F-GHGs in flat panel display manufacturing, the company has focused its GHG reduction efforts on these two areas.
- HannStar applied for GHG early action offset credits based on the Taiwan EPA's Principles for Promoting Greenhouse Gas Pilot and Offset Projects and the Announced GHG Emission Intensity for TFT-LCD Industry.
- In 2015, Taiwan's EPA awarded Hannstar 3.78 million tons of carbon credits for their early action in voluntary GHG reductions.

Participation in Broader F-GHG Reduction Efforts

- HannStar is a member of Taiwan's TFT-LCD Association (TTLA). The TTLA participates on behalf of Taiwan's LCD suppliers in the World Display device Industry Cooperation (WDICC), whose members have agreed to 30% F-GHG emission reductions by 2020 relative to 2010 levels.

Sources

HannStar "SF_6 Abatement Strategy in Taiwan". Presentation by Taiwan's Industrial Technology Research Institute (ITRI), 2004. Available at: www.epa.gov/electricpower-sf6/documents/conf04_lu.pdf.

TTLA presentation at APEC meeting, August 2012, Taiwan.

World Display device Industry Cooperation Committee Environmental Report. Available at http://home.jeita.or.jp/device/committee/pdf/Environmental%20Report_ENG_161110.pdf.

Suppliers Without Public Data in 2016

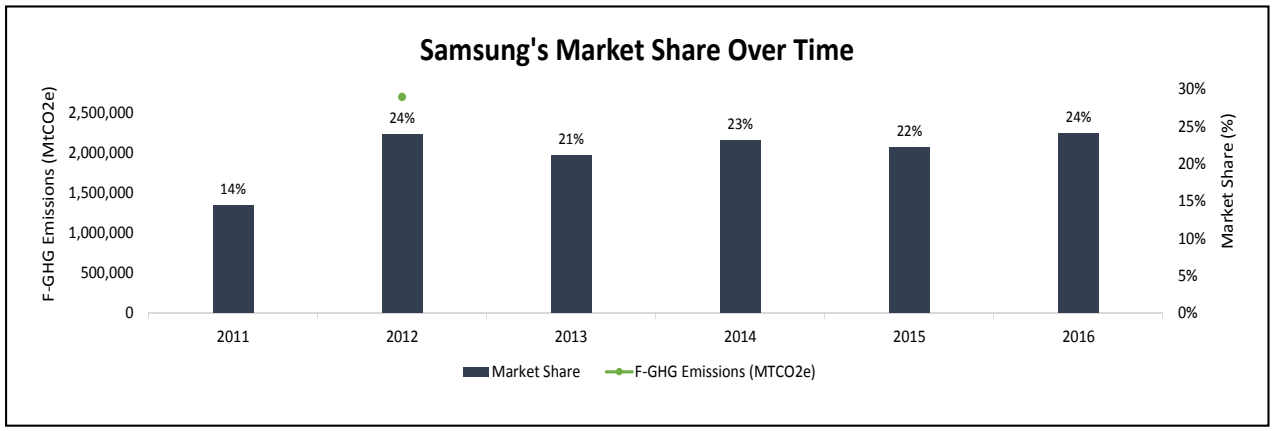
Samsung, BOE, China Star, and Infovision did not report public data in 2016. As a result:

- No information is available on these suppliers' F-GHG emission reduction activities, including on gases targeted, processes targeted, or approaches used.
- These suppliers do not publicly measure or verify F-GHG emissions.
- These suppliers do not have or disclose emission reduction goals and progress.
- No information is available on these suppliers' participation in broader F-GHG reduction efforts, except for Samsung, which is subject to Korea's regulatory requirements (i.e., the Korean Emissions Trading Scheme (K-ETS)) to reduce GHG emissions, though it is unclear if they are actively participating.

Below, the suppliers are listed based on their 2016 market share:

Samsung

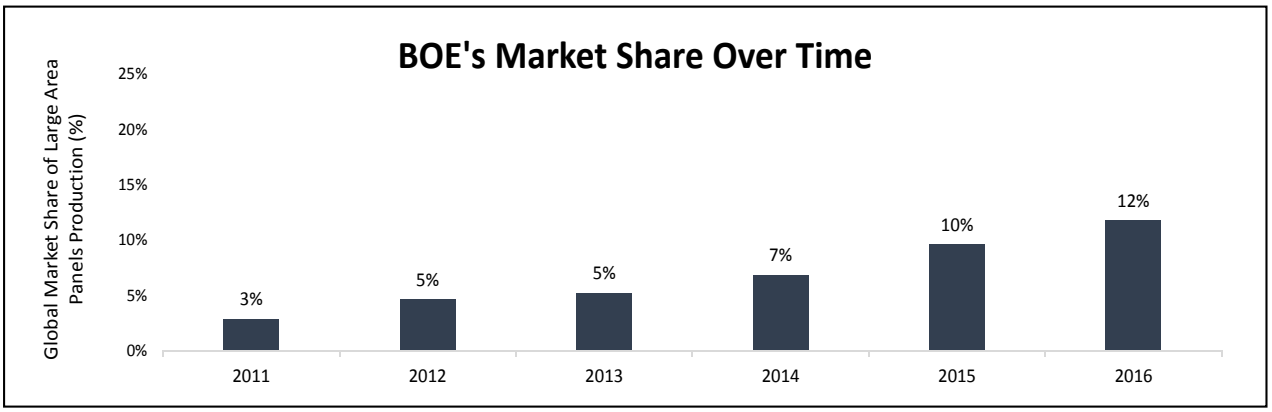
24% Market Share in 2016



Information for calendar year 2012 can be found in a previous profile, hence the inclusion of emissions data information for Samsung here.

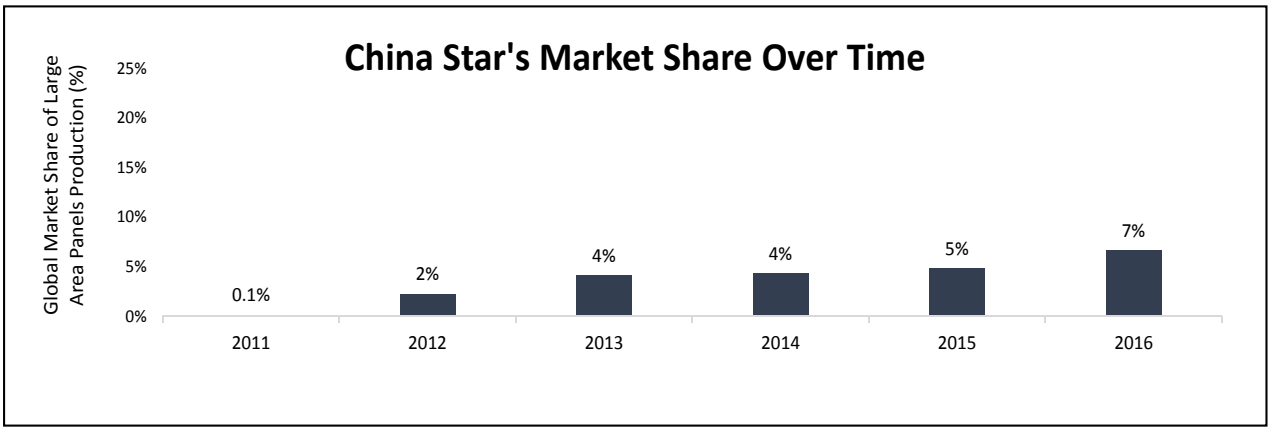
BOE

12% Market Share in 2016



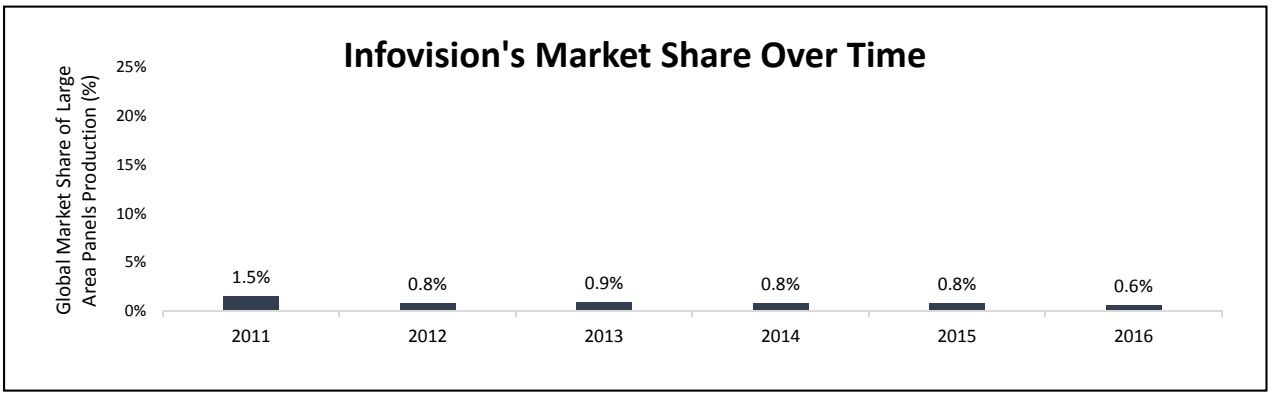
China Star

7% Market Share in 2016



Infovision

1% Market Share in 2016



Sources

Republic of Korea: An Emissions Trading Case Study. Available at
http://www.ieta.org/resources/2016%20Case%20Studies/Korean_Case_Study_2016.pdf