Overview of the Industrial Processes and Product Use Volume of the 2019 Refinement to the 2006 IPCC Guidelines

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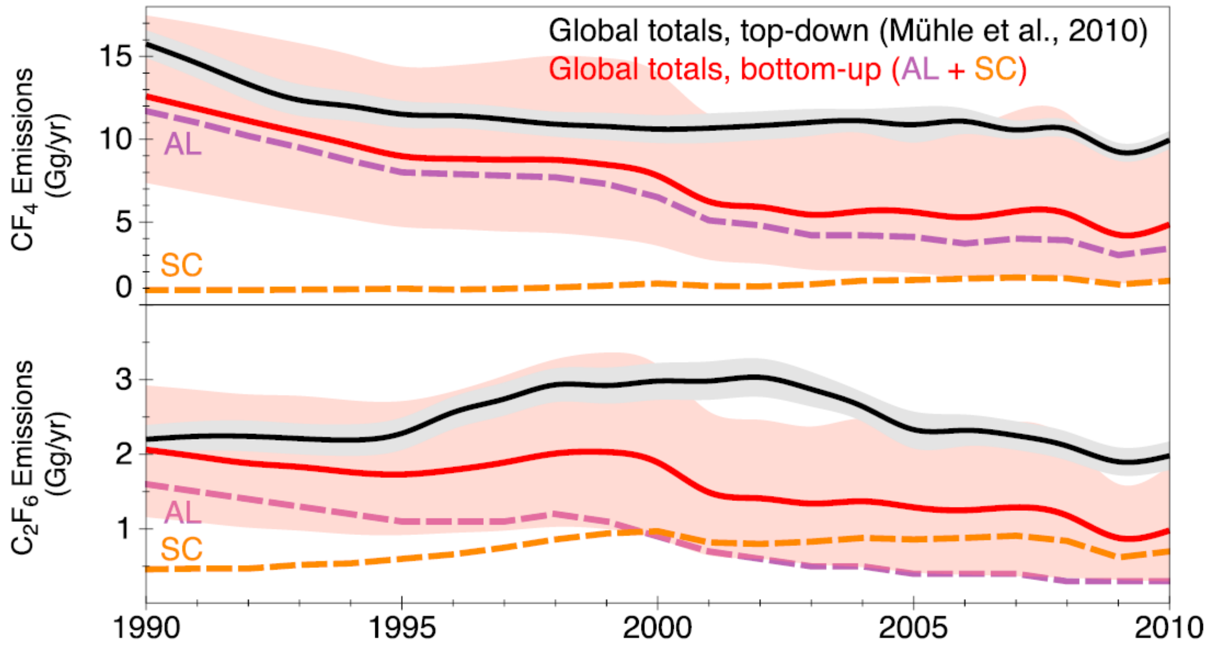
Why did guidance for Industrial Processes and Product Use need to be updated?

- New source categories emerged or were discovered
  - Production of rare earth metals, use of PFCs for waterproofing of circuit boards and textile treatment
- New emissions mechanisms for existing sources emerged or were discovered
  - Low-voltage anode effects for aluminium production
- Emission factors changed as technologies evolved
  - Electronics production
- New F-GHGs came into use
  - Unsaturated HFCs (HFOs) for RAC; additional gaseous and liquid fluorocarbons for electronics
- Emissions mechanisms and factors were better understood
  - Fluorochemical production, aluminium production
- Experience with Guidelines showed that they need to be clarified in some cases
  - Refrigeration and air conditioning, allocation of iron and steel emissions between Industrial Processes and Energy.

“Extra” PFC Emissions Observed in Atmosphere



Source: Kim, J., et al. (2014), “Quantifying aluminum and semiconductor industry perfluorocarbon emissions from atmospheric measurements,” *Geophys. Res. Lett.*, 41, 4787-4797, doi: 10.1002/2014GL059783.

Refinements to Guidance for Industrial Processes

Section or Chapter	Source Category	Emitted GHG(s)	Key Refinements
3.3	Nitric Acid Production	N_2O	Updated production process categories, Tier 2 default EFs
3.10	Fluorochemical Production	F-GHGs, N_2O	Updated Tier 1 default EFs; new methods for estimating emissions from equipment leaks, container venting
3.11	Hydrogen Production	CO_2	New guidance
4.2	Iron and Steel and Coke Production	CO_2, CH_4, N_2O	Updated default EFs, several new methods, and numerous clarifications and updates to better allocate emissions to IPPU vs. Energy while avoiding double-counting or overlooking emissions

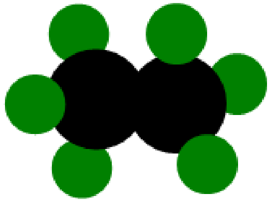
Refinements to Guidance for Industrial Processes (cont.)

Section or Chapter	Source Category	Emitted GHG(s)	Key Refinements
4.4	Primary Aluminium Production	PFCs, CO_2	For PFCs, updated smelting technology classes, new guidance for estimating emissions from low-voltage anode effects (LVAE), updated default EFs for Tier 1 and Tier 2, additional Tier 2 and Tier 3 methods; for CO_2, new guidance for alumina production
4.8	Rare Earth Metal Production	PFCs, CO_2	New guidance
6	Electronics Industry Emissions	Gaseous and liquid F-GHGs	Updated Tier 1 and 2 default EFs and Tier 2 and 3 methods, new Tier 2c and Tier 3b methods, new guidance on tracking gas consumption and improved guidance for accounting for gas abatement systems

Refinements to Guidance for Industrial Processes (cont.)

Section or Chapter	Source Category	Emitted GHG(s)	Key Refinements
7.5	Refrigeration and Air Conditioning	HFCs, PFCs	New “cook-book” style guidance on building an ODS substitute inventory (data sources and establishing the bank), new and updated tables regarding the identity and distribution of ODS substitutes by application and by substance for both developing and developed countries
8.3	Waterproofing of Electronic Circuits	F-GHGs	New guidance
Appendix 1	Textile Production	F-GHGs	New basis for future methodological development

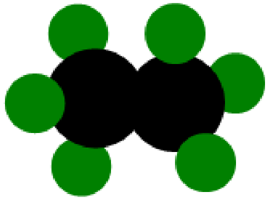
Fluorochemical Production: Background



Emissions of fluorinated GHGs occur during fluorochemical production, transformation, destruction, and related processes.

- Can include products and unintentionally generated by-products (e.g., HFC-23 from HCFC-22 production)
- May be vented or leaked from production, transformation, and destruction processes
- May be vented from returned cylinders that contain a “heel” of residual gas
- May be formed and/or released during destruction processes (e.g., CF_4)

Fluorochemical Production: Key Refinements



- Updated Tier 1 default emission factors (includes process vents, equipment leaks, and container venting)
- Added Tier 2 equation based on process mass balance
- Added Tier 3 guidance for estimating emissions from equipment leaks
- Added Tier 3 guidance for estimating emissions from returned cylinder/container venting
- Updated estimates of the uncertainty of the EFs

Fluorochemical Production: New Tier 1 EFs

TABLE 3.28A (NEW)
TIER 1 DEFAULT EMISSION FACTORS FOR FLUOROCHEMICAL PRODUCTION

Fluorochemical Produced	Emission Factor for each Emitted GHG (kg fluorinated GHG emissions/kg fluorochemical produced)	Uncertainty for default emission factor for fluorochemical production
SF_6	0.03 (SF_6)[a] 0.08 (SF_6)[b]	±50% (0.015 to 0.045) ±50% (0.04 to 0.12)
NF_3	0.02 (NF_3)[c] 0.03 (N_2O)[d] 0.01 (CF_4)[d]	±50% (0.01 to 0.03) ±50% (0.015 to 0.045) ±50% (0.005 to 0.015)
All other fluorochemicals	0.04 (see Table 3.28B for composition of emitted mass)[e]	-98% to +470% (0.001 to 0.2)[f]

[a] O'Connell, 2002. [b] Suizu, 1999. [c] Fthenakis, 2010. [d] Tasaka, 2004; 2007 [e]Annex 3.1

PFC Emissions from Primary Aluminium Production: Background

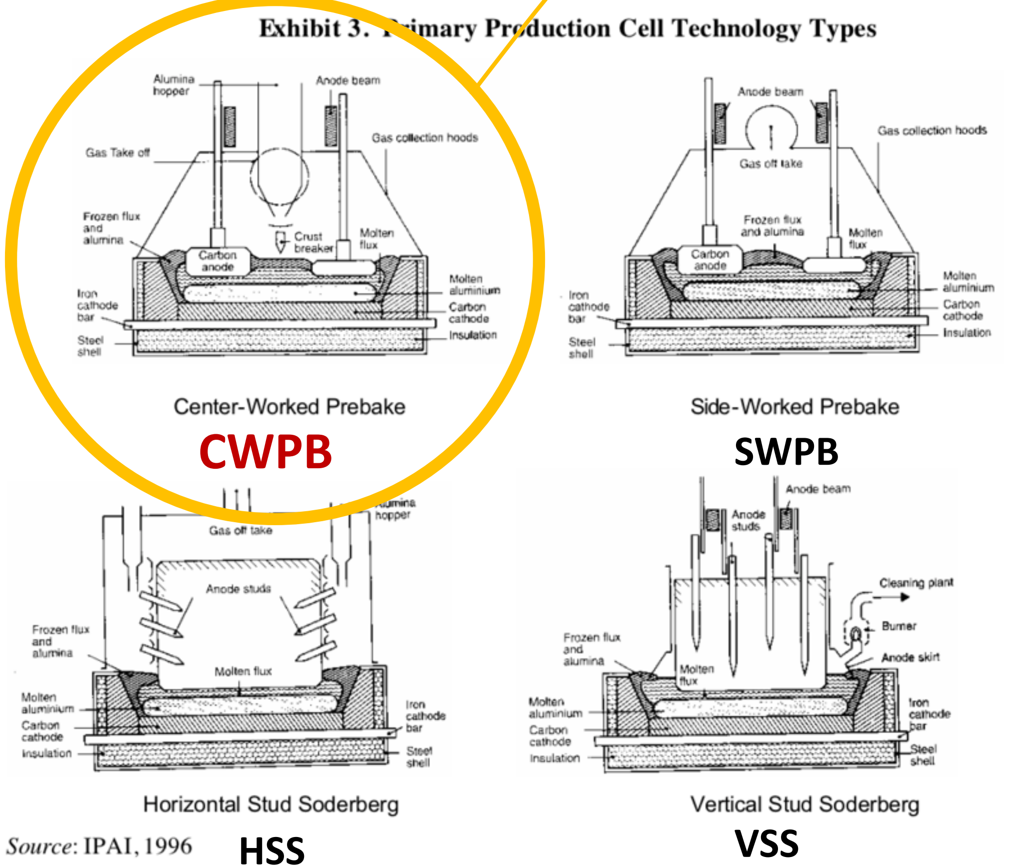
- PFCs emitted from both:
  - High-voltage anode effects (HVAE, >8V)
    - Addressed by 2006 IPCC Guidelines
  - Low-voltage anode effects (LVAE, <8V)
    - Newly addressed by 2019 Refinement
- Technology changes since 2006 have generally *decreased* HVAE emissions
- But technology changes since 2006 have *increased* LVAE emissions, especially for high-amperage (>350kA) Point-Fed Prebake (PFPB) with no automatic anode effect termination strategies

PFC Emissions from Primary Aluminium Production: Key Refinements

- Updated smelting technology classes
- Updated default emission factors for the Tier 1 method
- New guidance for estimating emissions from low-voltage anode effects (LVAE)
- Updated default emission factors for the existing Tier 2 and Tier 3 (now Tier 2a and Tier 3a) methods for estimating emissions from high-voltage anode effects (HVAE)
- New Tier 2b and Tier 3b methods for estimating emissions from HVAE that better account for the impact of anode effect duration
- New Tier 3_{DM} method for facility-specific direct measurement of total PFC emissions
- For CO2, new guidance has been added for estimating emissions from the production of alumina through the Bayer-Sinter and Nepheline processes

Aluminium: Summary of changes
Updated Technologies for PFCs

2006 Guidelines



Source: IPAI, 1996 HSS VSS

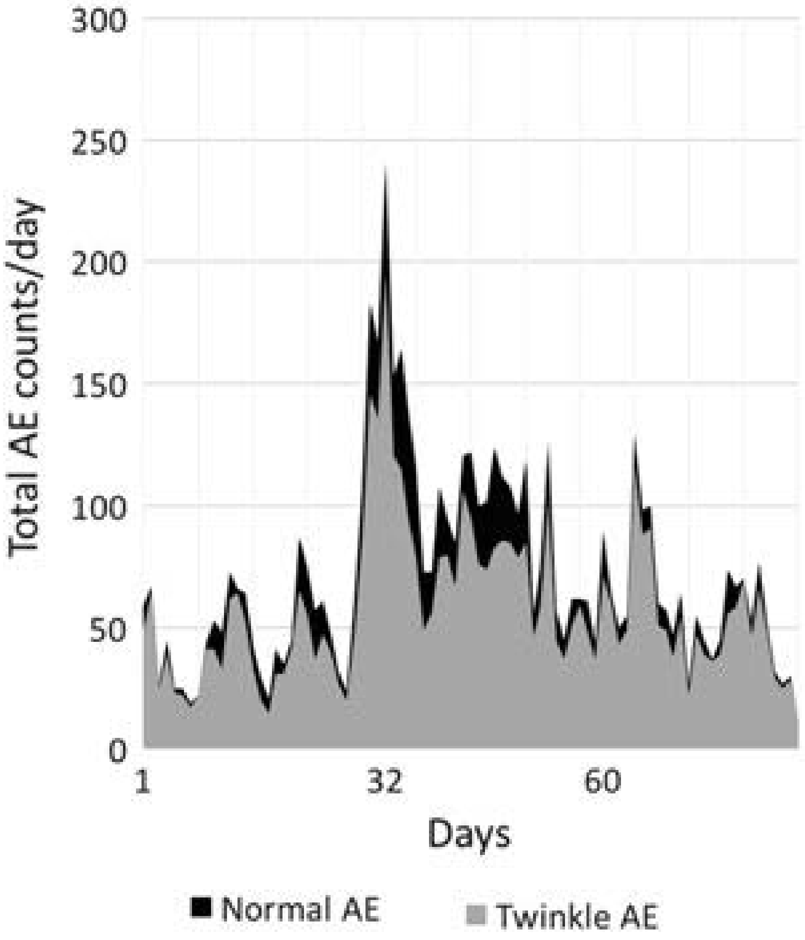
2019 Refinements

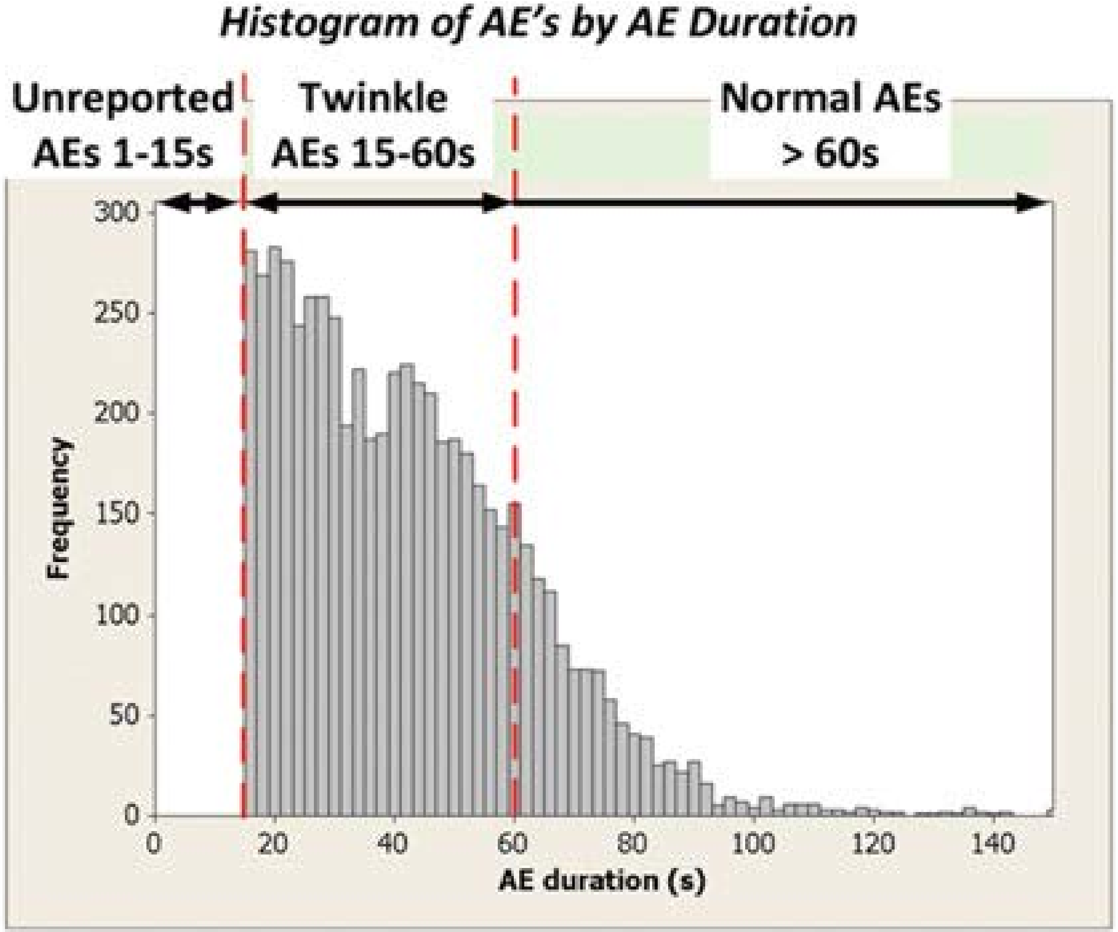
New technology classes from old **CWPB**

- **$PFPB_L$** (legacy) < 350kA older technology
- **$PFPB_M$** (modern) > 350kA, newer
- **$PFPB_{MW}$** (modern without AET) often >350kA, with *no* automatic AE termination strategies **OR with *non*-standard definitions of HVAE** (e.g. China)
  - Non-standard definition: HVAEs lasting 60 seconds or less (“twinkle” AEs) are not counted toward HVAE totals.

Not counting short-duration, “twinkle” HVAEs leads to underestimating HVAE frequency and total HVAE minutes. Thus, Tier 2 and 3 methods cannot be used when short-duration HVAE are not counted.

“Normal” & “Twinkle” HVAE Counts per Day



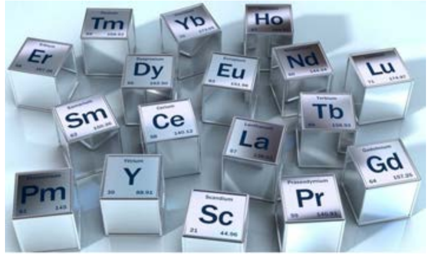


Source: Wong, David S., Xiping Chen, Bofeng Cai, Xin Bo, and Pernelle Nunez, “PFCs from the Chinese Aluminium Sector—Challenges in Emissions Accounting and Further Characteristics,” Light Metals 2018, The Minerals, Metals & Materials Series, https://doi.org/10.1007/978-3-319-72284-9_199

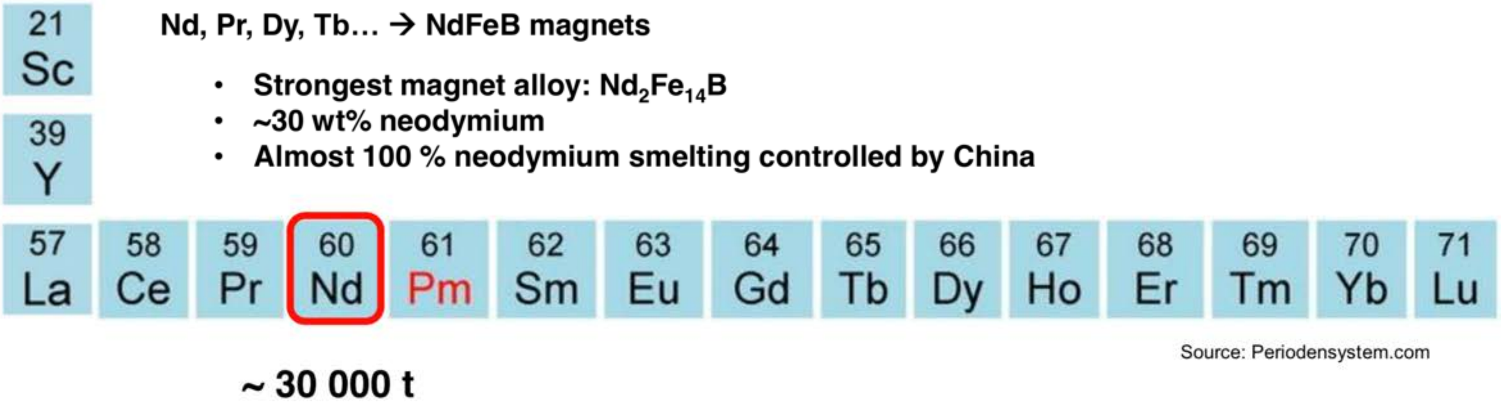
ALUMINIUM: SUMMARY OF ACCOUNTING METHODS FOR PFC EMISSIONS

Tier		Emission Source	Method Description	By	Cell Technology Applicable
1	1_{HVAE}	HVAE	Production-based default EF	Technology class	All technologies
	1_{LVAE}	LVAE	Production-based default EF	Technology class	All technologies
2	$2a_{HVAE}$	HVAE	Slope method	Technology class	All technologies **except** $\mathbf{PFPB_{MW}}$
	$2b_{HVAE}$	HVAE	Non-linear method	Technology class	$PFPB_M$, $PFPB_L$ and SWPB only
3	$3a_{HVAE}$	HVAE	Slope or Overvoltage method	Facility specific	All technologies **except** $\mathbf{PFPB_{MW}}$
	$3b_{HVAE}$	HVAE	Non-linear method	Facility specific	All technologies **except** $\mathbf{PFPB_{MW}}$
	3_{LVAE}	LVAE	LVAE/HVAE ratio or production-based factor	Facility specific	All technologies
	3_{CSU}	CSU	Cell start-up EF	Facility specific	All technologies
	3_{DM}	Total	Direct gas measurement	Facility specific	All technologies

PFCs from Rare Earth Metals Smelting: Background



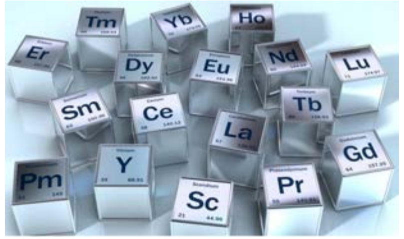
- Previously unaccounted for
- China represented >90% production in 2018
- Similar process to aluminium but less advanced
- Lack of supporting literature but a potential contributor to 'gap'
- No global RE industry body



Source: Periodensystem.com

Source: Reuters.com, 2015

Rare Earths: Summary of new GLs



EQUATION 4.37 (NEW)
PFC EMISSIONS FROM RARE EARTH METALS PRODUCTION (TIER 1 AND TIER 3)

$$E_{CF4} = \sum_i [(EF_{CF4,\, i} \ / \ 1000) \bullet MP_i]$$

and

$$E_{C2F6} = \sum_i [(EF_{C2F6,\, i} \ / \ 1000) \bullet MP_i]$$

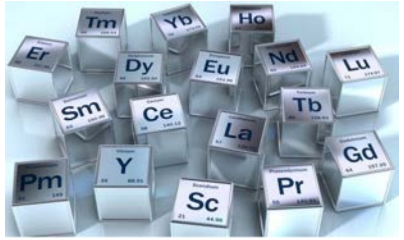
and

$$E_{C3F8} = \sum_i [(EF_{C3F8,\, i} \ / \ 1000) \bullet MP_i]$$

Total PFCs = production-based EF * metal production

Both Tier 1 (default EF) and Tier 3 (facility-specific EF) approaches

Rare Earths: Summary of new GLs



Tier 1: Two sets of default emission factors

- Based on two published industrial measurements

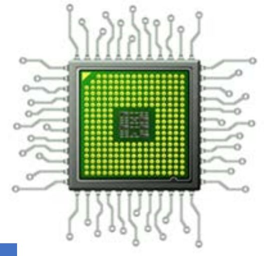
TABLE 4.28 (NEW)
TIER 1 DEFAULT EMISSION FACTORS AND UNCERTAINTY RANGES FOR THE CALCULATION OF PFC EMISSIONS FROM RARE EARTH PRODUCTION

	CF_4		C_2F_6		C_3F_8	
Rare Earth Metal, *i*	**EF_{CF4} (g/tonne RE metal)**	**Uncertainty Range [c] (+/-%)**	**EF_{C2F6} (g/tonne RE metal)**	**Uncertainty Range [c] (+/-%)**	**EF_{C3F8} (g/tonne RE metal)**	**Uncertainty Range [c] (+/-%)**
RE-iron alloys (Dy-Fe, etc) [a]	146.1	+/- 99%	14.6	+/- 99%	0.05	+/- 99%
Other-RE metals/alloys (Nd, Pr-Nd, La, etc) [b]	35.8	-54% / +30%	5.2	-95% / +108%	0.21	-52% / +30%

High melting-point RE-iron alloys, e.g. Dy-Fe

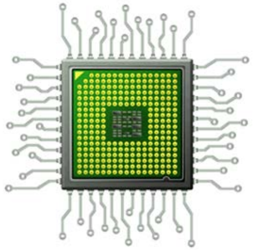
All other RE metals & alloys, e.g. Nd.

Electronics: Background



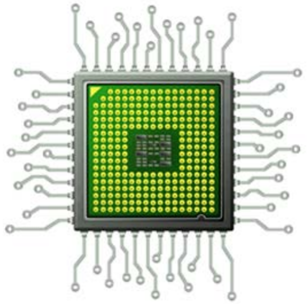
SOURCES AND TYPES OF GHGS EMITTED DURING ELECTRONICS MANUFACTURING (FROM TABLE 6.1 IN 2019 REFINEMENT)		
Source	**GHG(s) Emitted**	**Relevant Sections of Volume 3 of 2019 Refinement**
Incompletely utilized FC gases fed into plasma etching, wafer cleaning, and chamber cleaning processes	Multiple FC gases	6.2.1.1, 6.2.2.1
By-products formed from carbon-containing FC gases fed into plasma etching, wafer cleaning, and chamber cleaning processes	Multiple FC gases	6.2.1.1 (See especially Box 6.2), 6.2.2.1
By-products formed from fluorine-containing gases (e.g., NF_3, F_2, COF_2) fed into plasma etching, wafer, cleaning, and chamber cleaning processes that involve carbon-containing films	Multiple FC gases	6.2.1.1 (See especially Box 6.2 and discussion following Equation 6.6), 6.2.2.1

Electronics: Background (cont.)



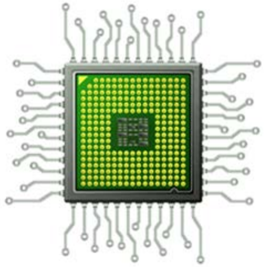
Sources and types of GHGs emitted during Electronics Manufacturing (From Table 6.1 in Refinement, Continued)		
Source	**GHG(s) Emitted**	**Relevant Sections of Volume 3 of 2019 Refinement**
By-product formed in some combustion-based FC abatement systems	CF_4	6.2.1.1 (Equation 6.7 for Tiers 2a and 2b, Equation 6.15 for Tiers 2c and 3a)
Incompletely utilized N_2O fed into thin film deposition and other (e.g., diffusion) processes	N_2O	6.2.1.1 (throughout)
Fluorinated liquids used for temperature control, device testing, cleaning substrate surfaces and other parts, and soldering	Multiple FC liquids	6.2.1.2, 6.2.2.2, (See especially Table 6.5)
FCs emitted during waterproofing of electronic circuits	Multiple FC gases	Chapter 8, section 8.3 (See discussion near Equation 8.22A)

Electronics: Key Refinements



- 2019 Electronics Chapter is a complete update of 2006 IPCC Guidelines.
- Takes into account the changes in manufacturing processes and equipment that have occurred in the electronics industry during the last 13 years.
  - Reflects the much larger set of experimental data available (as of 2018 compared to 2006) to calculate default emissions factors.
  - Covers additional gaseous and liquid F-GHGs and N_2O.
- Introduces several methodological refinements to increase accuracy and flexibility.
  - Updates simple Tier 2a and Tier 2b methods; adds more sophisticated Tier 2c method
  - Updates Tier 3a method; adds new Tier 3b stack testing method
  - Adds guidance on tracking gas consumption at facility-, process-, wafer-size levels
  - Improves guidance on accounting for gas abatement systems

Method description (Gaseous emissions)

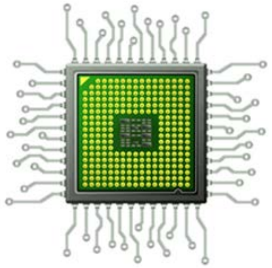


Ease of implementation

Methods	Activity Data	Description
Tier 1	Surface area of substrate used	Updated default semiconductor and display emission factors; new MEMs defaults
Tier 2a	Gas consumption by facility, stack system, process type, process, and/or wafer size, as applicable.	Refined method for semiconductors with no differentiation between wafer size Limited differentiation by process type Updated default emission factors and by-product factors
Tier 2b		Refined method for semiconductor - differentiation by wafer size (≤200 mm or 300 mm) Limited differentiation by process type Updated default emission factors and by-product factors
Tier 2c		New method with distinction by both substrate size (semiconductor) and process type (semiconductor, PV and display)
Tier 3a		Measured facility-specific emission factors at process level
Tier 3b		Measured facility-specific emission factors at stack level

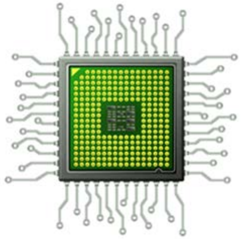
Accuracy

Electronics: Tracking Gas Consumption



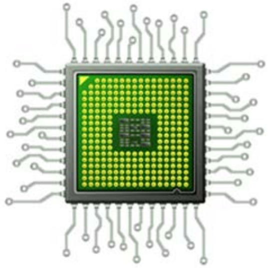
- Compared to the *2006 IPCC Guidelines*, the *2019 Refinement* provides additional guidance on how to track gas consumption and assign (or "apportion") it to different process types and (where necessary) different wafer sizes.
- Overall consumption is based on the annual change in the quantity of each gas stored on site, gas acquisitions, and gas disbursements.
- Gas may be apportioned by either
  - Using direct measurement to monitor gas consumption at the process type, stack system-, or facility-level (as appropriate), or
  - Developing and verifying a site-specific engineering model based on a quantifiable metric such as such as substrate passes or substrate starts.
- Tier 2a and Tier 2b methods require relatively little apportioning.

Electronics: Accounting for Fraction of Emissions Destroyed



- The Tier 2 and 3 methods account for the fraction of emissions destroyed by abatement equipment. This requires estimating the following parameters:
  - Fraction of emissions that are exhausted to abatement equipment
  - Destruction and removal efficiency (DRE) of abatement equipment
  - Uptime of abatement equipment

Electronics: Accounting for fraction of emissions destroyed—DRE of abatement equipment



- A new decision tree asks three key questions regarding the effectiveness of abatement equipment. If the answer to any question is "no," the default DRE cannot be used.
  - Are onsite emissions control technologies suitable for the gas to be abated?
  - Have emissions control technologies been tested and certified by the OEM(s) to meet the default DRE values indicated in Table 6.17?
  - Is emissions control equipment installed, maintained and operated per manufacturer's specifications?

Thank you for your attention!

- Any questions?

Additional Slides

Aluminium: Summary of changes

	2006				2019				
Tier	**Type**	**PFC Gas**	**Method**	**By**	**Tier**	**Type**	**PFC Gas**	**Method**	
1	HVAE	CF_4, C_2F_6	Production-based default emission factor	Technology class	**1_{HVAE}**	HVAE	CF_4, C_2F_6	Production-based default emission factor	
					1_{LVAE}	LVAE	CF_4	Production-based default emission factor	NEW
2	HVAE	CF_4, C_2F_6	Default slope factor x AEM/ cell-day x prod	Technology class	**2a HVAE**	HVAE	CF_4, C_2F_6	Default slope factor x AEM/cell-day x production	
	HVAE	CF_4, C_2F_6	Overvoltage		**2b HVAE**	HVAE	CF_4, C_2F_6	Non-linear accounting for AE duration	NEW
3	HVAE	CF_4, C_2F_6	Slope	Facility specific	**3a HVAE**	HVAE	CF_4, C_2F_6	Slope or Overvoltage	
					3b HVAE	HVAE	CF_4, C_2F_6	Non-linear	NEW
					3_{LVAE}	LVAE	CF_4	Ratio or production-based factor	NEW
	HVAE	CF_4, C_2F_6	Overvoltage		**3_{CSU}**	CSU	CF_4, C_2F_6	Cell start-up factor	NEW
					3_{DM}	Total	CF_4, C_2F_6	Direct measurement	NEW