Industrial Production and Other Product Use

29th April 2024

Presenter: Sina Wartmann, Ricardo Energy & Environment

(supported by US EPA)

Session 1: Sector Overview

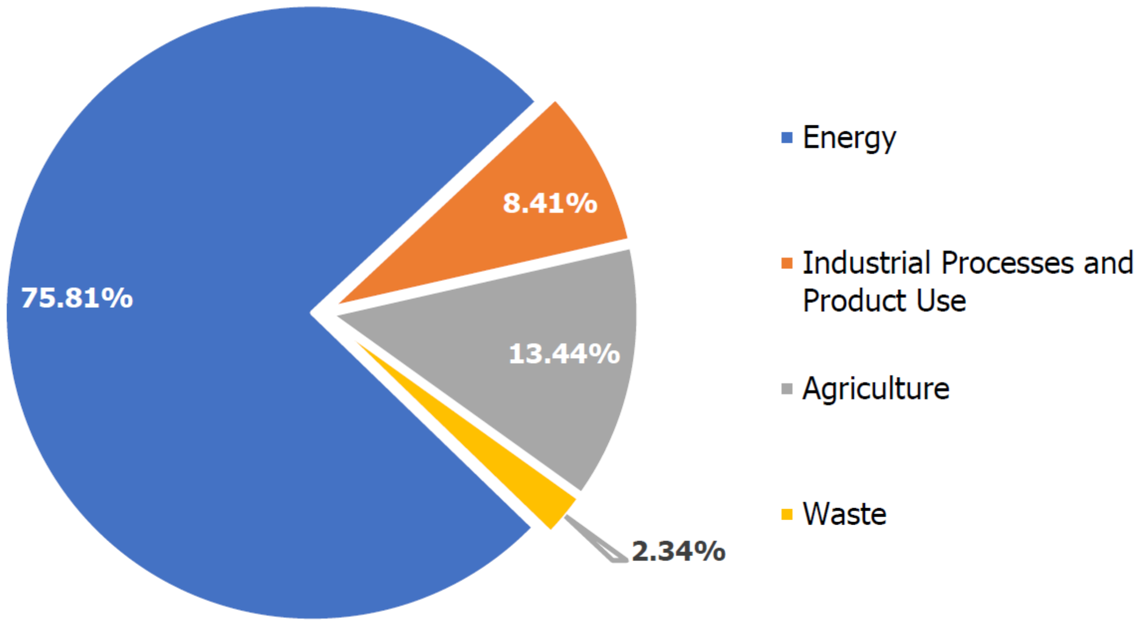
AGENDA

Time	Contents	Presenters
08:30-9:30	US Experience Compiling ODS Substitutes	Virtual Session: Dave Godwin, US EPA
09:30-10:30	IPPU Sector: Mineral, Chemical and Metal Industry: IPCC 2006 Guidelines, Mandatory Requirements and Flexibility Provisions (including Hands on exercise)	Mausami Desai and Lisa Hanle
10:30-10:45	Tea/Coffee Break	
10:45-11:45	IPPU Sector: Mineral, Chemical and Metal Industry: IPCC 2006 Guidelines, Mandatory Requirements and Flexibility Provisions (including Hands on exercise)	Lisa Hanle
11:45-13:00	Lunch Break	
13:00-15:00	IPPU Sector: Mineral, Chemical and Metal Industry – moving forwards: Tier 2 requirements for key categories, data collection, improvements, enhancing category-level quality control	Sina Wartmann
15:00-15:15	Tea/Coffee Break	
15:15-17:00	IPPU Sector: Electronics Industry, Non- Energy Products from Fuels and Solvent Use, ODS and Other Product manufacture and use:	Sina Wartmann + Stephanie Bogle

IMPORTANCE FOR DEVELOPING COUNTRY PARTIES

- IPPU sector is often considered to be less significant compared to Energy and AFOLU – in India, it accounted for 8.41% in 2019
- Situation varies from country to country
- IPPU sources may become significant in the future as developing countries' economies and industries grow
- Inclusion of F-gases estimates can contribute significantly to the IPPU emissions and influence the total estimates
- IPPU emissions estimation is important to find opportunities for GHG abatement

Contribution of sectors to India's total national GHG emissions (2019)



Industrial Processes and Product Use overview

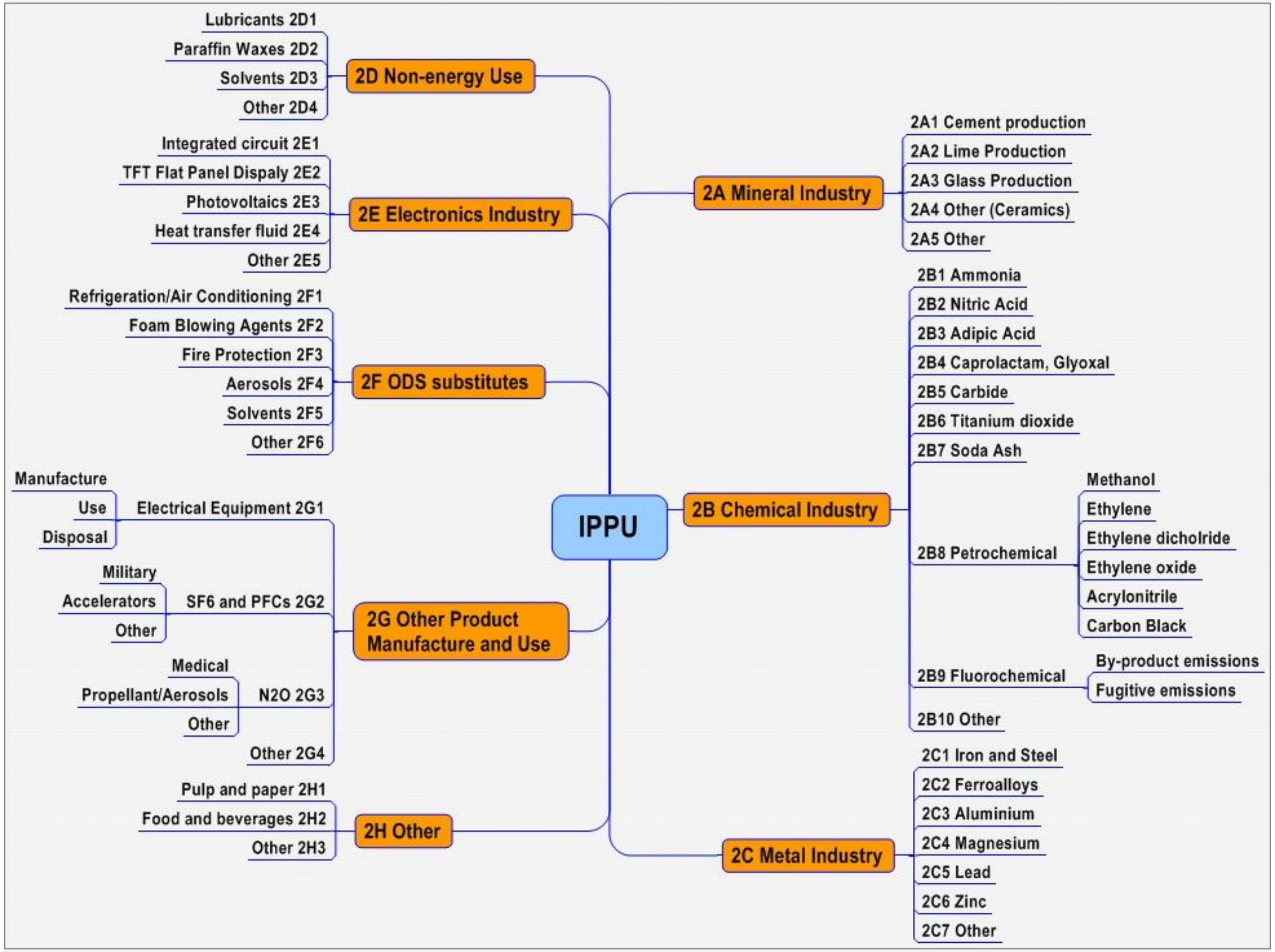
Subsectors:

- 2.A Mineral Industry Emissions
- 2.B Chemical Industry Emissions
- 2.C Metal Industry Emissions
- 2.D Non-Energy Products from Fuels and Solven Use
- 2.E Electronics Industry Emissions
- 2.F Emissions of Fluorinated Subsitutes for Ozone Depleting substances
- 2.G Other Product Manufacture and Use

Gases:

CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, NF_3,

IPPU CATEGORIES



How are GHGs emitted?

Keep in mind: Fuel consumption for production processes is accounted for under the energy sector

- GHG emissions
  - Chemical / physical reactions during production processes (CO_2, N_2O, CH_4, CF_4, C_2F_6, HFC-23, NF_3)
    - cement, lime production
    - aluminum production
  - Use of GHGs in production processes or as part of products (HFCs, PFCs, SF_6)
    - cooling agents in refrigeration/air conditioning
    - N_2O for anesthesia
    - semiconductor production

General Calculation Methodologies

$$TOTAL_{ij} = AD_j \times EF_{ij}$$

Where:

TOTALij = Process emission (tonnes) of gas i, from industrial sector j

ADj = Amount of activity or production of process material (activity data) in industrial sector j (tonnes/yr)

EFij = Emission factor (EF) associated with gas i, per unit of activity in industrial sector j (tonne/tonne)

- In addition, mass-balance approaches exist for certain processes, e.g. Iron and Steel, ODS substitutes
- 3 Tier approaches exist for most categories:

Tier	Activity Data	Emission Factor
1	National or default	Default
2	National-level	Country-specific
3	Installation-level/modelled	Installation specific / application specific

- Note: A Tier 2 approach is required for key categories in principle

India's IPPU emissions by subsector(2011-2019)

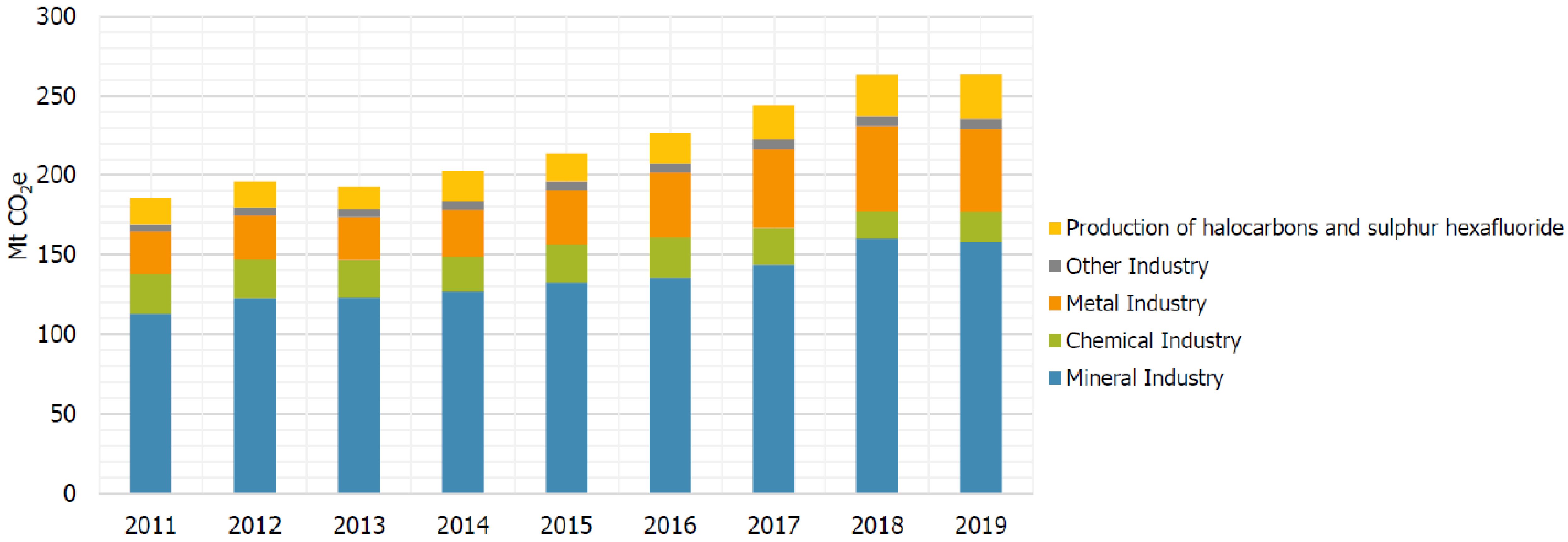
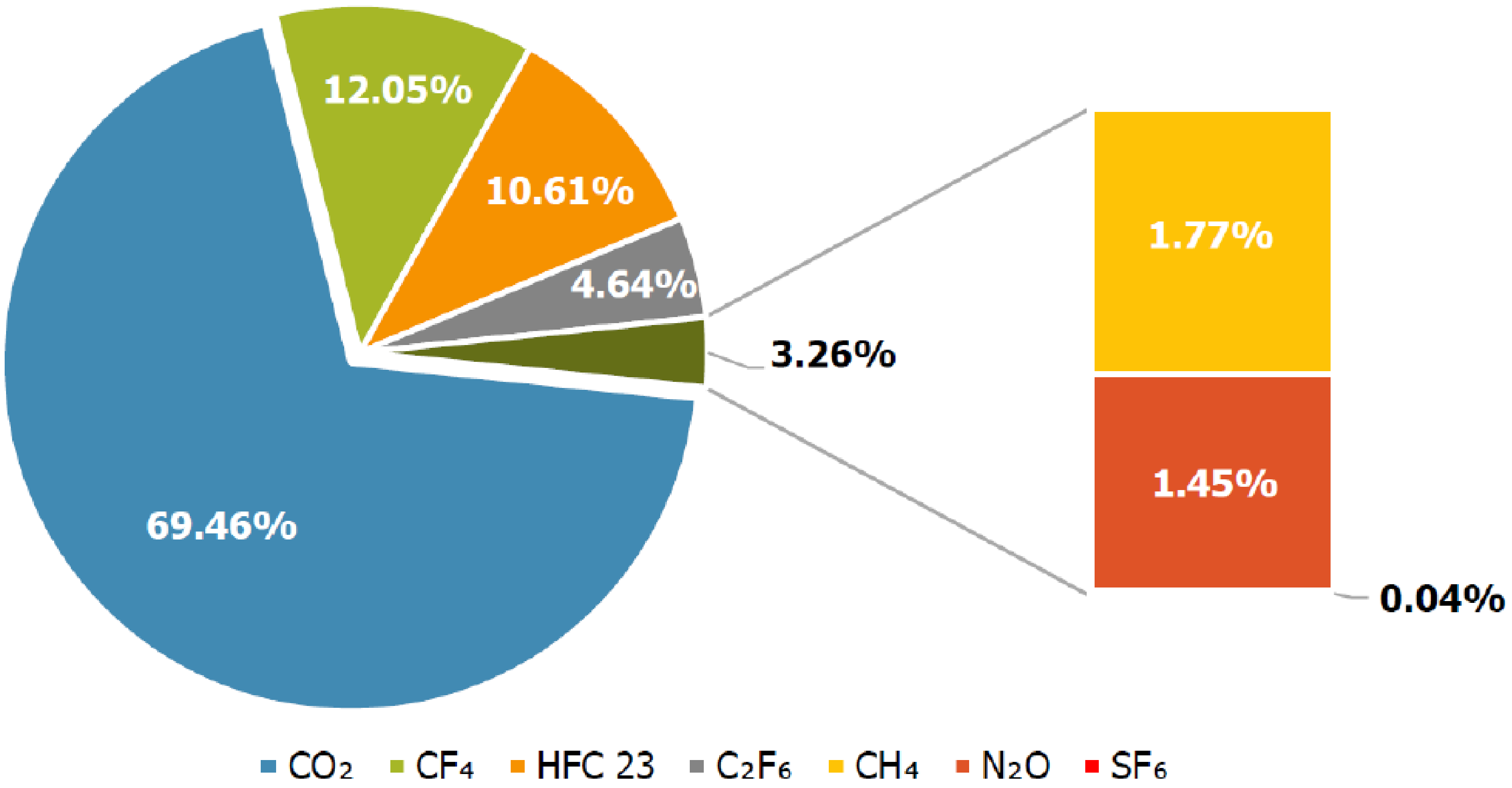
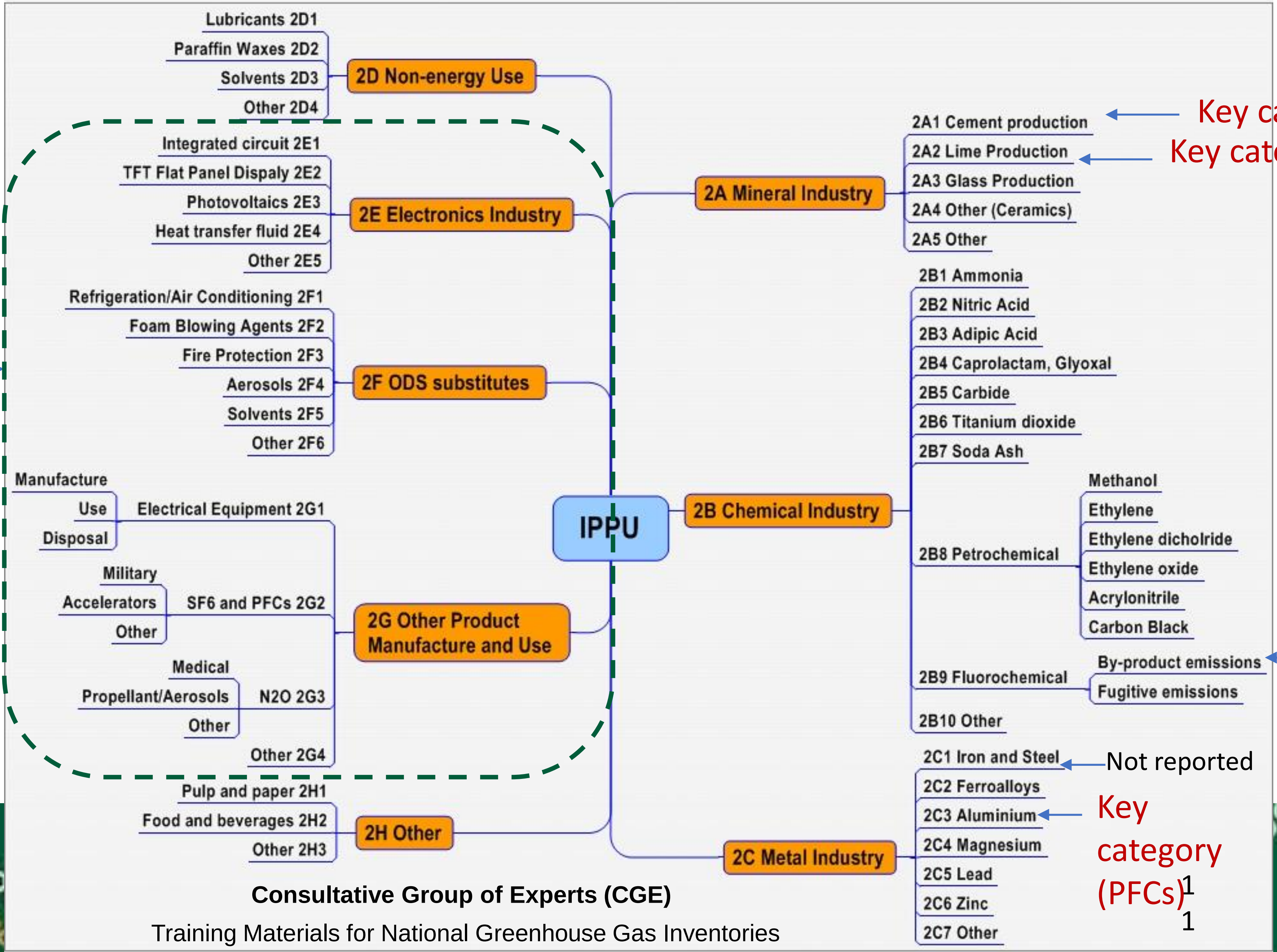


Figure 2.12: Industrial Processes and Product Use: GHG emissions ($MtCO_2e$) per subcategory, 2011-2019

India's IPPU emissions by gas (2011-2019)



IPPU Categories in India's 3rd National Communication



HIGH-LEVEL POTENTIAL AREAS FOR IMPROVEMENT

- To improve completeness, estimating emissions of
  - 2.C.1 Iron and steel
  - 2.E Electronics Industry
  - 2.F ODS substitutes
  - 2.G Other product manufacture and use
- To improve accuracy, moving to Tier 2 for key categories
  - CO_2 from 2.A.2 lime production
  - CF_4 and C_2F_6 from 2.C.3 aluminium production
  - HFC-23 from 2.B.9 Fluorochemical production (HCFC-22 production)
- To improve transparency
  - Allocating emissions correctly (HFC-23 emissions to 2.B.9, not 2.E)
  - Reporting information on Tiers used for gases other than CO_2, CH_4, N_2O
  - Providing additional category-level information on methodologies and data sources in NID (e.g. aluminium)
  - Reporting transparently on sources of country-specific EFs

Potential overlaps between IPPU and other sectors

Sectors	
Energy/IPPU	Where fuels are combusted for energy use, the emission from fuel uses should be counted under Stationary Energy. Fuels might be used as feedstock or reducing agent in production processes (i.e. not with the aim of power/heat production), e.g. coke providing carbon for the steelmaking process. In this case emissions are to be reported under IPPU. A few typical cases: • Where fuels obtained directly or indirectly from production feedstock are combusted at the same source category (e.g. combusting of blast furnace gas in a steelworks), the resulting emissions will be allocated to IPPU • Where derived fuels are transferred for combustion in another source category (e.g. blast furnace gas transferred to a brick production for heat generation), the emissions should be reported in Stationary Energy • If heat is released from chemical reaction not for energy use, the emissions from chemical reaction should be reported as an industrial process in IPPU
Energy/IPPU	Where lubricants, paraffin waxes, bitumen/asphalt, and solvents (2D – Non-energy products from fuels and solvent use) are combusted for the purpose of further use/disposal with energy recovery, related emissions are reported under the energy sector
Agriculture	Carbonates might be used for mineral and metal production under IPPU, but also for liming of soils in agriculture
Agriculture	Urea can be produced from CO_2 captured from ammonia production. These CO_2 emissions are deducted from the ammonia emission totals. CO_2 is emitted once the urea is used, and thus emissions are allocated to the category where the use takes place, e.g. CO_2 from urea used as fertilizer in the agriculture sector is allocated to agriculture.
Waste/IPPU	Where lubricants, paraffin waxes, bitumen/asphalt, and solvents are incinerated without energy recovery, related emissions are reported under the waste sector

Typical Data Issues in IPPU

- Statistics often not available for relevant AD
- Hospitals, research facilities might use N_2O/SF_6, no public reporting on use/emissions
- Importers, manufacturers and/or industry associations are typically relevant data sources, but often have very limited insight into data needs
- Industry will often not have data at hand or understand data needs
- Confidentiality issues with industry data
- Data reported by industry only includes emissions, no AD/EF
- Available data has often not undergone QA/QC, there is often not information on uncertainties

IPPU Activity Data: Confidentiality

Find solutions to overcome data holders' concerns by:

- explaining the intended use of the data
- agreeing, in writing, to the level at which it will be made public
- identifying the increased accuracy that can be gained through its use in inventories
- offering cooperation to derive a mutually acceptable data sets
- and/or giving credit/acknowledgement in the inventory to the data provided

Reporting Requirements: GHG Inventories

Methodologies, parameters and data

- Shall use 2006 IPCC GL
- Should use same methods and consistent AD and EF over time series, splicing technique

Time series consistency & Recalculations

- Shall perform recalculations
- Should elaborate categories not reported and notation keys

Assessment of Completeness

- Shall report previously reported categories
- May use 'NE" for insignificant categories to a threshold*

Key category analysis

- Shall apply 95% threshold for level and trend for base and most recent year

Uncertainty

- Shall quantitatively and qualitatively assess uncertainty for level for starting and latest year, and trend

QA/QC

- Shall elaborate QA/QC plan and implement approach 1 QA/QC checks
- Should apply category specific checks; a peer review, and reference approach

Requirements with flexibility provisions

Mandatory "shall" requirements

Non-mandatory "Should"/ "may" requirements

CRT Tables for IPPU – Sectoral Report

Year
Submission
Country

TABLE 2(I) SECTORAL REPORT FOR INDUSTRIAL PROCESSES AND PRODUCT USE
(Sheet 1 of 1)

Back to Index

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO_2	CH_4	N_2O	HFCs [1]	PFCs [1]	Unspecified mix of HFCs and PFCs [1]	SF_6	NF_3	NO_x	CO	NMVOC	SO_x	Total GHG emissions [2]
	(kt)			CO_2 equivalent (kt) [3]			(kt)						CO_2 equivalents (kt) [3]
2. Total industrial processes													
2.A. Mineral industry													
2.A.1. Cement production													
2.A.2. Lime production													
2.A.3. Glass production													
2.A.4. Other process uses of carbonates													
2.B. Chemical industry													
2.B.1. Ammonia production													
2.B.2. Nitric acid production													
2.B.3. Adipic acid production													
2.B.4. Caprolactam, glyoxal and glyoxylic acid production													
2.B.5. Carbide production													
2.B.6. Titanium dioxide production													
2.B.7. Soda ash production													
2.B.8. Petrochemical and carbon black production													
2.B.9. Fluorochemical production													
2.B.10. Other													
2.C. Metal industry													
2.C.1. Iron and steel production													
2.C.2. Ferroalloys production													
2.C.3. Aluminium production													
2.C.4. Magnesium production													
2.C.5. Lead production													
2.C.6. Zinc production													
2.C.7. Other													
2.D. Non-energy products from fuels and solvent use [4]													
2.D.1. Lubricant use													
2.D.2. Paraffin wax use													
2.D.3. Other													
2.E. Electronics industry													
2.E.1. Integrated circuit or semiconductor													
2.E.2. TFT flat panel display													
2.E.3. Photovoltaics													
2.E.4. Heat transfer fluid													
2.E.5. Other													
2.F. Product uses as substitutes for ODS													
2.F.1. Refrigeration and air conditioning													
2.F.2. Foam blowing agents													
2.F.3. Fire protection													
2.F.4. Aerosols													
2.F.5. Solvents													
2.F.6. Other applications													
2.G. Other product manufacture and use													
2.G.1. Electrical equipment													

CRT Tables for IPPU: Sectoral Background Data (CO_2, CH_4, N_2O)

TABLE 2(I).A-H SECTORAL BACKGROUND DATA FOR INDUSTRIAL PROCESSES AND PRODUCT USE
Emissions of CO_2, CH_4 and N_2O
(Sheet 1 of 1)

Year
Submission
Country

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GREENHOUSE GAS SOURCE AND SINK CATEGORIES	ACTIVITY DATA		IMPLIED EMISSION FACTORS [1]			EMISSIONS [2]			RECOVERY/CAPTURE [3,4]			
	Production/Consumption quantity		CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2 fossil	CO_2 biogenic [6]	CH_4	N_2O
	Description [5]	(kt)	(t/t)			(kt)			(kt)			
2.A. Mineral industry												
2.A.1. Cement production	(e.g. cement or clinker production)											
2.A.2. Lime production												
2.A.3. Glass production												
2.A.4. Other process uses of carbonates												
2.A.4.a. Ceramics												
2.A.4.b. Other uses of soda ash												
2.A.4.c. Non-metallurgical magnesium production												
2.A.4.d. Other *(please specify)*												
2.B. Chemical industry												
2.B.1. Ammonia production [7]												
2.B.2. Nitric acid production												
2.B.3. Adipic acid production												
2.B.4. Caprolactam, glyoxal and glyoxylic acid production												
2.B.4.a. Caprolactam												
2.B.4.b. Glyoxal												
2.B.4.c. Glyoxylic acid												
2.B.5. Carbide production												
2.B.5.a. Silicon carbide												
2.B.5.b. Calcium carbide												
2.B.6. Titanium dioxide production												
2.B.7. Soda ash production												
2.B.8. Petrochemical and carbon black production												

CRT Tables for IPPU: Sectoral Report F-gases

TABLE 2(II) SECTORAL REPORT FOR INDUSTRIAL PROCESSES AND PRODUCT USE - EMISSIONS OF HFCs, PFCs, SF_6 AND NF_3
(Sheet 1 of 1)

Year
Submission
Country

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GREENHOUSE GAS SOURCE AND SINK CATEGORIES	HFC-23	HFC-32	HFC-41	HFC-43-10mee	HFC-125	HFC-134	HFC-134a	HFC-143	HFC-143a	HFC-152	HFC-152a	HFC-161	HFC-227ea	HFC-236cb	HFC-236ea	HFC-236fa	HFC-245ca	HFC-245fa	HFC-365mfc	Unspecified mix of HFCs (1)	Total HFCs	CF_4	C_2F_6	C_3F_8	C_4F_{10}	$c\text{-}C_4F_8$	C_5F_{12}	C_6F_{14}	$C_{10}F_{18}$	$c\text{-}C_3F_6$	Unspecified mix of PFCs (1)	Total PFCs	Unspecified mix of HFCs and PFCs (1)	SF_6	NF_3
	(t)																			CO_2 equivalents (kt) (2)		(t)									CO_2 equivalents (kt) (2)			(t)	(t)
2. Total actual emissions of halocarbons (by chemical), SF_6 and NF_3																																			
2.B. Chemical industry																																			
2.B.9. Fluorochemical production																																			
2.B.9.a. By-product emissions																																			
2.B.9.b. Fugitive emissions																																			
2.B.10. Other																																			
2.C. Metal industry																																			
2.C.3. Aluminium production																																			
2.C.4. Magnesium production																																			
2.C.7. Other																																			
2.E. Electronics industry																																			
2.E.1. Integrated circuit or semiconductor																																			
2.E.2. TFT flat panel display																																			
2.E.3. Photovoltaics																																			
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2.E.5. Other																																			
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2.F.3. Fire protection																																			
2.F.4. Aerosols																																			
2.F.5. Solvents																																			
2.F.6. Other applications																																			
2.G. Other product manufacture and use																																			
2.G.1. Electrical equipment																																			
2.G.2. SF_6 and PFCs from other product use																																			
2.G.4. Other																																			
2.H. Other																																			
	CO_2 equivalents (kt) (2)																																		
Total emissions (3)																																			
2.B. Chemical industry																																			
2.C. Metal production																																			

CRT Tables for IPPU: Sources of fluorinated substances – Sheet 1

TABLE 2(II).B-H SECTORAL BACKGROUND DATA FOR INDUSTRIAL PROCESSES AND PRODUCT USE
Sources of fluorinated substances
(Sheet 1 of 2)

Year
Submission
Country

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GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Gas *(please specify)* One row per substance	ACTIVITY DATA		IMPLIED EMISSION FACTORS [1]	EMISSIONS [2]	RECOVERY [3,4]
		Description	(t)	(kg/t)	(t)	(t)
2.B. Chemical industry						
2.B.9. Fluorochemical production						
2.B.9.a. By-product emissions						
2.B.9.a.i. Production of HCFC-22	e.g. HFC-23	Production of HCFC-22				
2.B.9.a.ii. Other *(please specify - one row per substance)*		Production of the main substance				
2.B.9.b.Fugitive emissions [5]						
2.B.9.b.i. Production of HFC-134a	e.g. HFC-134a	Production of that substance				
2.B.9.b.ii.Production of SF_6	e.g. SF_6	Production of that substance				
2.B.9.b.iii.Production of NF_3	e.g. NF3	Production of that substance				
2.B.9.b.iv. Other *(please specify - one row per substance)*						
		Production of that substance				
2.C. Metal production						
2.C.3. Alminium production						
2.C.3.a. By-product emissions	e.g. CF_4, C_2F_6	Production of primary aluminium				
2.C.3.b. F-gases used in foundries [6]	e.g. SF_6	Amount of aluminium casted				
2.C.4. Magnesium production [7]	e.g. SF_6, HFC	Amount of magnesium casted				
2.C.7. Other						
Drop-down list:						
2.C.7.a. Rare earths production						
2.C.7.b. Other *(please specify - one row per substance)*						

CRT TABLES FOR IPPU: SOURCES OF FLUORINATED SUBSTANCES – SHEET 2

TABLE 2(II).B-H SECTORAL BACKGROUND DATA FOR INDUSTRIAL PROCESSES AND PRODUCT USE
Sources of fluorinated substances
(Sheet 2 of 2)

Year
Submission
Country

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GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Gas *(please specify)* *One row per substance*	ACTIVITY DATA *Amount*			IMPLIED EMISSION FACTORS [1]			EMISSIONS [2]			RECOVERY [3,4]
		Filled into new manufactured products	In operating systems (average annual stocks)	Remaining in products at decommissioning	Product manufacturing factor	Product life factor	Disposal loss factor	From manufacturing	From stocks	From disposal	
		(t)			%			(t)			
2.F. Product uses as substitutes for ODS											
2.F.1. Refrigeration and air-conditioning											
2.F.1.a. Commercial refrigeration	e.g. HFC-134a, 365mfc, HFC-43-10mee										
2.F.1.b. Domestic refrigeration	e.g. HFC-134a										
2.F.1.c. Industrial refrigeration	e.g. HFC-152a										
2.F.1.d. Transport refrigeration	e.g. HFC-125										
2.F.1.e. Mobile air-conditioning	e.g. HFC-143a										
2.F.1.f. Stationary air-conditioning	e.g. HFC-32										
2.F.2. Foam blowing agents	e.g. HFC-23										
2.F.2.a. Closed cells	e.g. HFC-236fa										
2.F.2.b. Open cells	e.g. HFC-245fa										
2.F.3. Fire protection	e.g. HFC-227ea										
2.F.4. Aerosols											

Thank You for your Attention!

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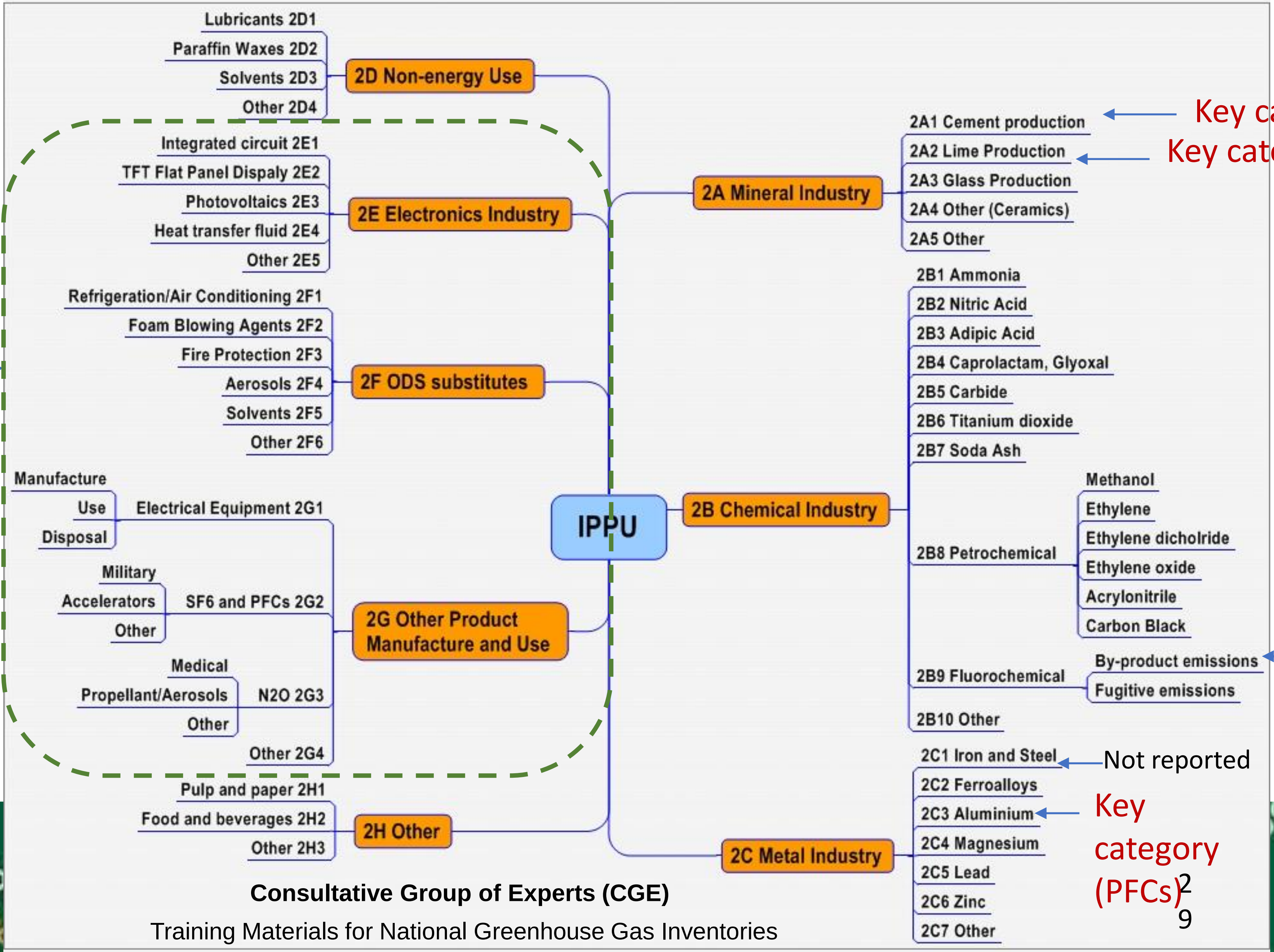
Session 2: Mineral, Chemical and Metal production

Overview

- Overview of categories and tiers used
- Category-specific topics
  - \- Cement sector:
    - Cement kiln dust
    - Use of steel slag, fly ash
  - \- Tier 2 for lime production: hydraulic and hydrated lime production?
  - \- Carbonates:
    - Might there be CO2 emissions from flue gas desulphurisation?
    - Are there other uses of carbonates beyond cement, lime, glass, ceramics?
  - \- Including CO_2 and CH_4 emissions from iron and steel production
  - \- Moving towards Tier 2 for PFCs in aluminium production
  - \- Further issues identified during the morning session
- Overarching quality control approaches for the IPPU sector

IPPU Categories in India's 3RD National Communication

Not included in 3NC



Key category (CO_2)

Key category (CO_2)

Key category (HFC-23)

Not reported

Key category (PFCs)

India's IPPU Methodologies

Sector	Pollutants	Tier	Key Category
2A1 Cement Production	CO_2	T2	2A1 CO2 (4.04%)
2A2 Lime Production	CO_2	T1	2A2 CO2 (0.98%)
2A3 Glass Production	CO_2	T2	
2A4 Other Process Uses of Carbonates (ceramics)	CO_2	T2	
2A5 Other	NE	-	-
2B1 Ammonia Production	CO_2	T2	
2B2 Nitric Acid Production	N_2O	T2	
2B4 Caprolactam Production	N_2O	T1	
2B5 Calcium Carbide Production	CO_2	T1	
2B6 Titanium Dioxide Production	CO_2	T1	
2B7 Soda Ash Production	CO_2	T1	
2B8 Carbon Black Production	CO_2, CH_4	T2, T1	
2B8 Methanol Production	CO_2, CH_4	T1, T1	

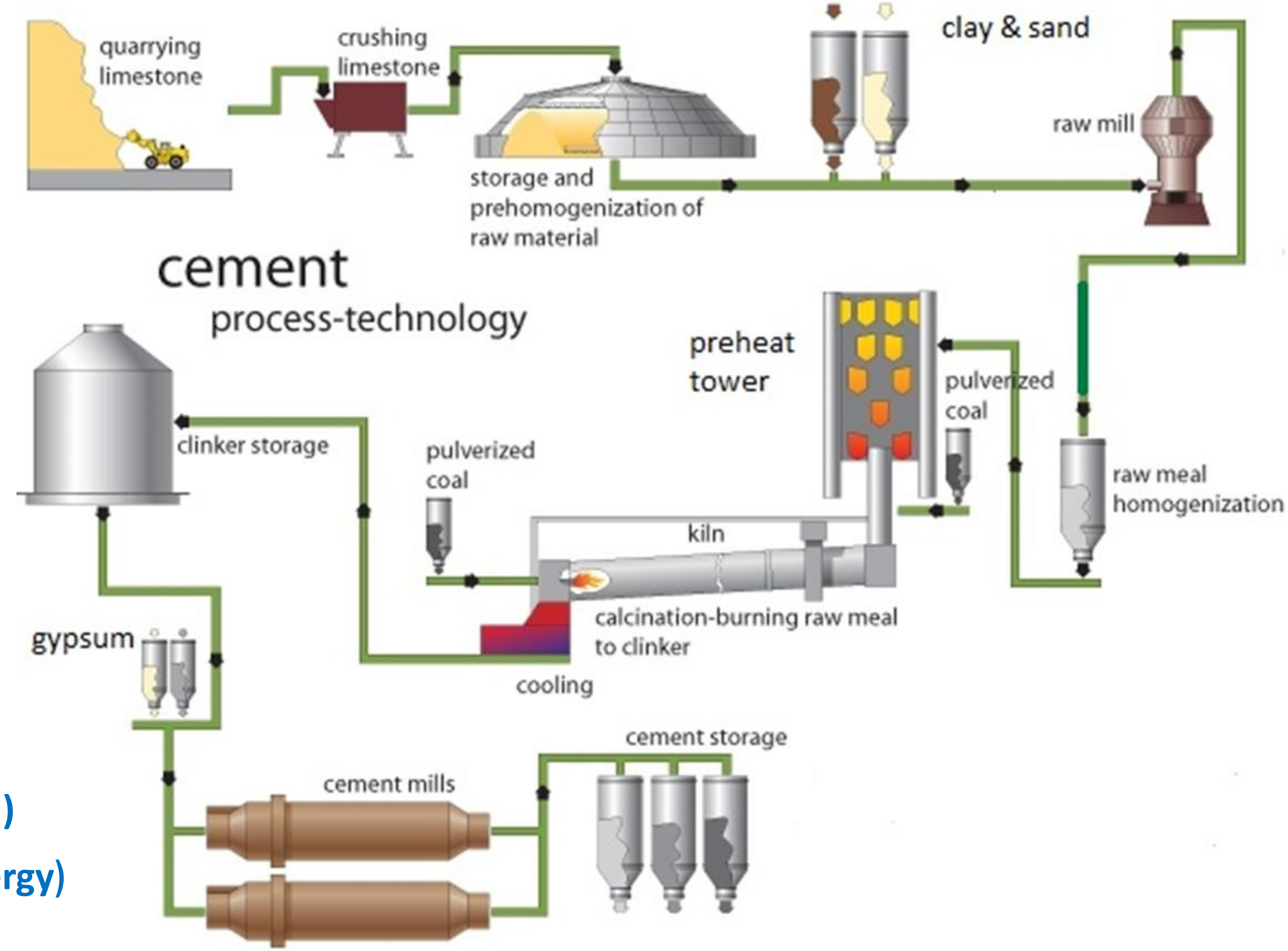
Sector	Pollutants	Tier	Key Category
2B8 Ethylene Production	CO_2, CH_4	T1,T1	
2B8 EDC and VCM Production	CO_2	T1	
2B8 Ethylene Oxide Production	CO_2, CH_4	T1,T1	
2B8 Acrylonitrile Production	CO_2, CH_4	T1,T1	
2B9 HCFC-22 Production	HFC-23	T1/T2	
2B9 Emissions from production of other fluorinated compounds	CFC-11,CFC-12,CFC-113, HFC123	T1, T1, T1, T?	
2C2 Ferroalloy Production	CO_2, CH_4	T1,T1	
2C3 Aluminium Production	CO_2, PFCs, HFC-23, HCFC-22	T2, T1, T1, T1	2C3, CF (1.40%)
2C4 Magnesium Production	CO_2, SF_6	T1, T1	
2C5 Lead Production	CO_2	T1	
2C6 Zinc Production	CO_2	T1	
2D1 Lubricant Use	CO_2	T1	
2D2 Paraffin Wax Use	CO_2	T1	
2E Production of halocarbons and SF_6			2E HFC (0.89%) ?
2H1 pulp and paper	CH_4		

2A: Mineral Industry

- Transformation of carbonate-contained compounds – limestone, dolomite, etc. *($CaCO_3$, $MgCO_3$, Na_2CO_3)*
- CO_2 Emissions

Code	Category
2A1:	**Cement Production**
2A2:	**Lime Production**
2A3:	**Glass Production**
2A4:	**Other Process Uses of Carbonates**
2A4a:	Ceramics
2A4b:	Other Uses of Soda Ash
2A4c:	Non Metallurgical Magnesia Production
2A4d:	Other
2A5:	**Other**

2A1: Cement Production



<u>Calcination:</u> $CaCO_3$ *+(Heat)* = $CaO+CO_2$ (IPPU)

<u>Combustion</u>: Coal/Gas+O_2=CO_2 *+(Heat)* (Energy)

Image: applied from DCMAC: http://www.dscrusher.com/solutions/production-line/sand-cement-cogeneration-production-line.html *(as of March, 1 , 2015)*

CO_2 FROM CEMENT PRODUCTION (TIER 2)

Tier 2 includes a correction addition for emissions associated with Cement Kiln Dust (**CKD**) not recycled to the kiln which is considered to be 'lost' and associated emissions are not accounted for by the clinker:

$$CO_2 \text{ Emissions} = M_{cl} \times EF_{cl} \times CF_{CKD}$$

$$CF_{CKD} = 1 + (Md / Mcl) * Cd * Fd * (EFc / EFcl)$$

CFCKD - *emissions correction factor for CKD, dimensionless*
Md - *weight of CKD not recycled to the kiln, tonnes*
Mcl - *weight of clinker produced, tonnes*
Cd - *fraction of original carbonate in the CKD (i.e., before calcination), fraction*
Fd - *fraction calcination of the original carbonate in the CKD, fraction*
EFc - *emission factor for the carbonate, tonnes CO_2/tonne carbonate*
EFcl - *emission factor for clinker uncorrected for CKD, tonnes CO_2/ tonne clinker (i.e., 0.51)*

2A2 Lime Production – Tier 2

- As Tier 1, based on stoichiometric ratios between CO_2 and carbonates contained
- Differentiates between high calcium, dolomitic and hydraulic lime
- Necessary to correct for share of high calcium lime and dolomitic lime further processed to hydrated lime (in case of no info – assume 0%)
- Consideration of lime kiln dust, similar to cement kiln dust (in case of no info – assume 2%)

Equation 2.6

Tier 2: Emissions based on national lime production data by type

$$CO_2\ Emissions = \sum_i \left(EF_{lime,i} \bullet M_{l,i} \bullet CF_{lkd,i} \bullet C_{h,i}\right)$$

CO2 Emissions = emissions of CO2 from lime production, tonnes
EF lime,i = emission factor for lime of type *i*, tonnes CO2/tonne lime (see Equation 2.9)
Ml,i = lime production of type *i*, tonnes
CF lkd,i = correction factor for LKD for lime of type *i*, dimensionless, this correction can be accounted for in a similar way as for CKD (Equation 2.5, but omitting the factor (Efc/EFcl))
Ch,i = correction factor for hydrated lime of the type *i* of lime, dimensionless
i = each of the specific lime types listed in Table 2.4

2A2 Lime Production – CO_2

Tier applied: T1
Key Category: Yes

Equation 2.6
Tier 2: Emissions based on national lime production data by type

$$CO_2\ Emissions = \sum_i (EF_{lime,i} \bullet M_{l,i} \bullet CF_{lkd,i} \bullet C_{h,i})$$

Where:

CO_2 Emissions = emissions of CO_2 from lime production, tonnes

$EF_{lime,i}$ = emission factor for lime of type *i*, tonnes CO_2/tonne lime (see Equation 2.9)

$M_{l,i}$ = lime production of type *i*, tonnes

$CF_{lkd,i}$ = correction factor for LKD for lime of type *i*, dimensionless
This correction can be accounted for in a similar way as for CKD (Equation 2.5, but omitting the factor (Ef_c/EF_{cl}))

$C_{h,i}$ = correction factor for hydrated lime of the type *i* of lime, dimensionless (See discussion under Section 2.3.1.3, Choice of Activity Data.)

i = each of the specific lime types listed in Table 2.4

Data needed
Optional data

	T1 Method	T2 Method
Activity Data	• **Data on marketed and non-marketed lime production**	• **Disaggregated data for types of non-hydrated lime produced (high-calcium lime, dolomitic lime, hydraulic lime)** • *Data on any non-carbonate sources of CaO*
EF and parameters	• Default values for type of lime produced • Default value for proportion of hydrated lime	• *LKD ratio to lime production (dependent on production type)*

2B: Chemical Industry

Code	Category	Default EF		
		CO_2	N_2O	CH_4
2B1:	Ammonia Production	X		
2B2:	Nitric Acid Production		X	
2B3:	Adipic Acid Production		X	
2B4:	Caprolactam, Glyoxal and Glyoxylic Acid Production		X X X	
2B5:	Carbide Production - SiC - CaC_2	 X X		X
2B6:	Titanium Dioxide Production	X		
2B7:	Soda Ash Production	X		

2B: Chemical Industry

Code	Category	Default EF		
		CO_2	CH_4	F-gases
2B8:	**Petrochemical and Carbon Black Production**			
2B8a:	Methanol	X	X	
2B8b:	Ethylene	X	X	
2B8c:	Ethylene Dichloride and Vinyl Chloride Monomer	X X	X	
2B8d:	Ethylene Oxide	X	X	
2B8e:	Acrylonitrile	X	X	
2B8f:	Carbon Black	X	X	
2B9:	**Fluorochemical Production**			
2B9a:	By-product Emissions			X
2B9b:	Fugitive Emissions			X

CALCULATING EMISSIONS FROM CHEMICAL INDUSTRY

Mass of produced chemical × **Chemical or facility specific emission factor** = **Emissions**

For detailed calculation methodology for specific chemicals see *2006 IPCC guidelines for national greenhouse gas inventories, volume 3: industrial processes and product use, chapter 3: chemical industry emissions*

2B1: Ammonia Production

CO_2 associated with urea production & use:

- 2006 GL: CO_2 recovered in the ammonia production process for urea production should be deducted from CO_2 emissions from 2B1 Ammonia Production

CO_2 emissions from urea use/incineration should be reported in the category where they occur, e.g.:

- Use of urea-based catalysts (Energy – Road Transport)
- Urea application to agricultural soils (AFOLU)
- Incineration of urea-based products (Waste)

2C: Metal Industry

Code	Category	CO_2	CH_4	F-gases
2C1:	Iron and Steel Production	X	X	
2C2:	Ferroalloys Production	X	X	
2C3:	Aluminium Production	X		X
2C4:	Magnesium Production	X		X
2C5:	Lead Production	X		
2C6:	Zinc Production	X		
2C7:	Other			

Coke production: (Energy)

Coal + (*Heat*) = Coke + Carbon Dioxide

Iron Production: (IPPU)

Coke + Iron Ore = Iron + Carbon Dioxide

Combustion: (IPPU)

Coke + Oxygen = Carbon Dioxide + (*Heat*)

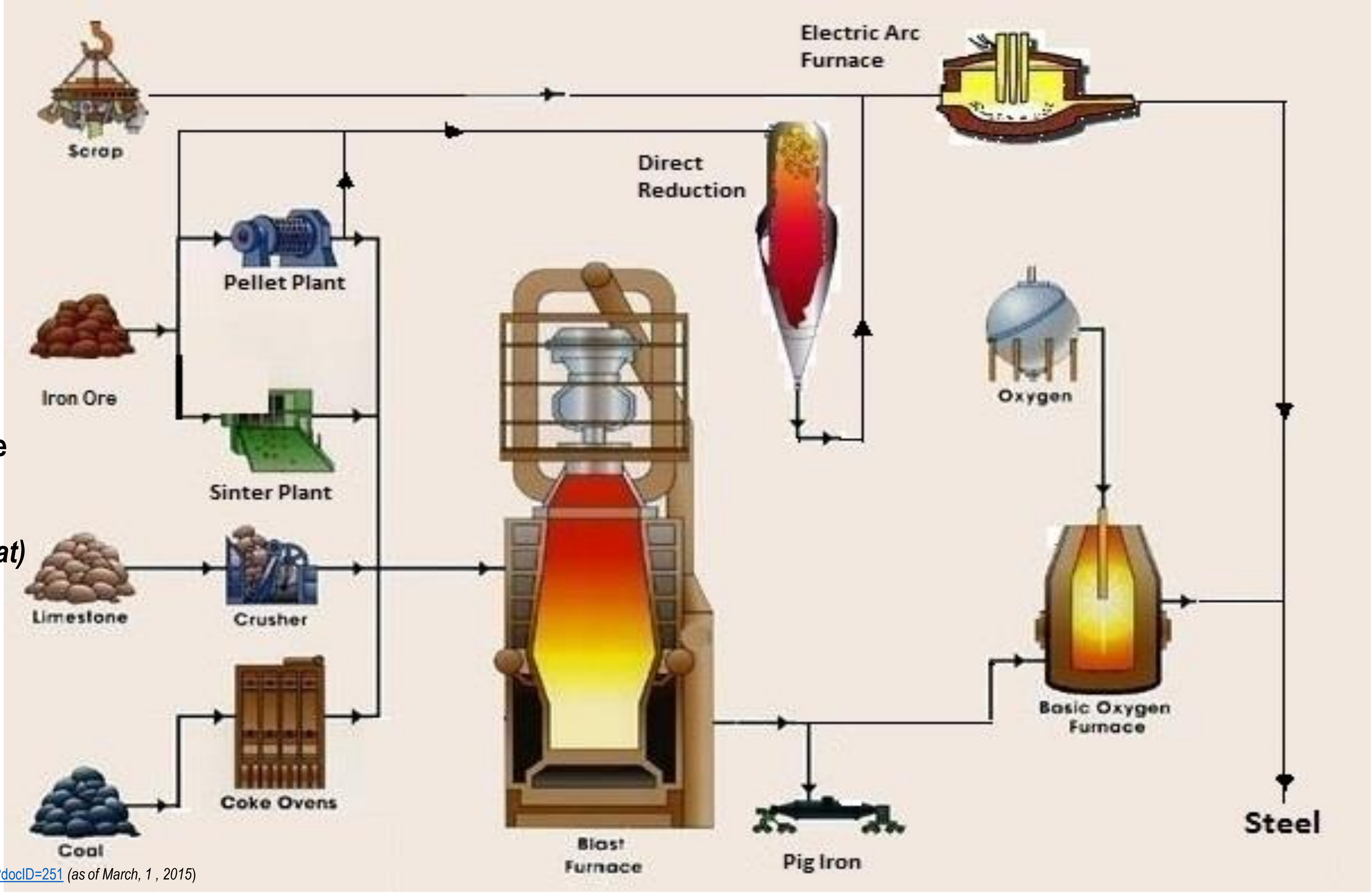


Image: applied from MetalPass http://www.metalpass.com/metaldoc/paper.aspx?docID=251 *(as of March, 1 , 2015)*

2C1: CO_2 from Iron and Steel Production (Tier 1)

CO_2 emissions from Iron & Steel production:

$$CO_2 \text{ Emissions} = \Sigma(AD_i \times EF_i)$$

AD_i - quantity of material *i*, tonnes
EF_i - emission factor for production of material *i*, tonnes CO_2/tonne material *i* produced

Material i
Crude steel from Basic Oxygen Furnace
Crude steel from Electric Arc Oxygen Furnace
Crude steel from Open Hearth Furnace
Pig iron not converted to steel
Direct reduced iron
Sinter
Pellet
Coke Oven (should be reported in Energy)

CO_2 EMISSIONS FROM IRON AND STEEL PRODUCTION (TIER 1)

Basic oxygen furnaces × BOF emission factor + Electric arc furnace × EAF emission factor + Open hearth furnace × OHF emission factor = Non-energy CO_2 Emissions

pig iron, tonnes × Pig iron emission factor = Non-energy CO_2 Emissions

DRI, tonnes × DRI emission factor = Non-energy CO_2 Emissions

sinter, tonnes × SI emission factor = Non-energy CO_2 Emissions

pellet, tonnes × SI emission factor = Non-energy CO_2 Emissions

→ Total non-energy CO_2 Emissions

Material i
Crude steel from Basic Oxygen Furnace
Crude steel from Electric Arc Oxygen Furnace
Crude steel from Open Hearth Furnace
Pig iron not converted to steel
Direct reduced iron
Sinter
Pellet
Coke Oven (should be reported in Energy)

2C1: CO_2 FROM IRON AND STEEL PRODUCTION (TIER 2)

EQUATION 4.9
CO_2 EMISSIONS FROM IRON & STEEL PRODUCTION (TIER 2)

$$E_{CO2,non-energy} = \left[PC \bullet C_{PC} + \sum_a (COB_a \bullet C_a) + CI \bullet C_{CI} + L \bullet C_L + D \bullet C_D + CE \bullet C_{CE} + \sum_b (O_b \bullet C_b) + COG \bullet C_{COG} - S \bullet C_S - IP \bullet C_{IP} - BG \bullet C_{BG} \right] \bullet \frac{44}{12}$$

Tier 2: While Tier 1 focuses on production outputs, Tier 2 considers

- input materials like coke, limestone, dolomite as well as
- carbon contents of inputs and outputs

Where, for iron and steel production:
ECO_2, non-energy = emissions of CO2 to be reported in IPPU Sector, tonnes
PC = **quantity of coke consumed in iron** and steel production (not including sinter production), tonnes
COBa = quantity of onsite coke oven by-product *a*, consumed in blast furnace, tonnes
CI= **quantity of coal directly** injected into blast furnace, tonnes
L = **quantity of limestone consumed** in iron and steel production, tonnes
D = **quantity of dolomite consumed** in iron and steel production, tonnes
CE = **quantity of carbon electrodes consumed** in EAFs, tonnes
Ob = **quantity of other carbonaceous and process material *b*, consumed** in iron and steel production, such
as sinter or waste plastic, tonnes
COG= **quantity of coke oven gas consumed** in blast furnace in iron and steel production, m3 (or other unit
such as tonnes or GJ. Conversion of the unit should be consistent with Volume 2: Energy)
S = quantity of steel produced, tonnes
IP = quantity of iron production not converted to steel, tonnes
BG = quantity of blast furnace gas transferred offsite, m3 (or other unit such as tonnes or GJ. Conversion
of the unit should be consistent with Volume 2: Energy)
Cx = **carbon content of material input or output** *x*, tonnes C/(unit for material *x*) [e.g., tonnes C/tonne]

2C3. Aluminium production – CO_2 emissions (Tier 1)

Equation 4.20
Process CO_2 emissions from anode and/or paste consumption (Tier 1 method)

$$E_{CO2} = EF_P \bullet MP_P + EF_S \bullet MP_S$$

Where:

E_{CO2} = CO_2 emissions from anode and/or paste consumption, tonnes CO_2

EF_P = Prebake technology specific emission factor (tonnes CO_2/tonne aluminium produced)

MP_P = metal production from Prebake process (tonnes Al)

EF_S = Søderberg technology specific emission factor (tonnes CO_2/tonne aluminium produced)

MP_S = metal production from Søderberg process (tonnes Al)

2C3. Aluminium production – CO_2 emissions (Tier 2/3)

- Differentiated by technology: Prebake and Søderberg process
- General assumption: carbon content of net anode consumption / paste consumption emitted as CO_2
- Tier 2 uses typical industry values for impurities
- Tier 3 uses actual concentrations of impurities

Example: Søderberg process

Equation 4.24[6]

CO_2 emissions from paste consumption (Tier 2 and Tier 3 methods)

$$E_{CO2} = \left(PC \bullet MP - \frac{CSM \bullet MP}{1000} - \frac{BC}{100} \bullet PC \bullet MP \bullet \frac{S_p + Ash_p + H_p}{100} - \frac{100 - BC}{100} \bullet PC \bullet MP \bullet \frac{S_c + Ash_c}{100} - MP \bullet CD \right) \bullet \frac{44}{12}$$

E_{CO2} = CO_2 emissions from paste consumption, tonnes CO_2
MP = total metal production, tonnes Al
PC = paste consumption, tonnes/tonne Al
CSM = emissions of cyclohexane soluble matter, kg/tonne Al
BC = binder content in paste, wt %
S_p = sulphur content in pitch, wt %
Ash_p = ash content in pitch, wt %
H_p = hydrogen content in pitch, wt %
S_c = sulphur content in calcined coke, wt %
Ash_c = ash content in calcined coke, wt %
CD = carbon in skimmed dust from Søderberg cells, tonnes C/tonne Al
44/12 = CO_2 molecular mass : carbon atomic mass ratio, dimensionless

2C3. Aluminium production – PFCs Emissions

Tier 1 uses technology-based default EFs for 4 main production technologies:

- *Centre-Worked Prebake (CWPB),*
- *Side-Worked Prebake (SWPB),*
- *Horizontal Stud Søderberg (HSS)*
- *Vertical Stud Søderberg (VSS)*

Table 4.15
Default emission factors and uncertainty ranges for the calculation of PFC emissions from aluminium production by cell technology type (Tier 1 method)

Technology	CF_4		C_2F_6	
	EF_{CF4} (kg/tonne Al)[a]	Uncertainty Range (%)[b]	EF_{C2F6} (kg/tonne Al)[c]	Uncertainty Range (%)[d]
CWPB	0.4	-99/+380	0.04	-99/+380
SWPB	1.6	-40/+150	0.4	-40/+150
VSS	0.8	-70/+260	0.04	-70/+260
HSS	0.4	-80/+180	0.03	-80/+180

Tier 2 based on direct measurements of PFCs for the 4 technologies and using 2 different methods:

- *Slope*
- *Overvoltage*

Table 4.16
Technology specific slope and overvoltage coefficients for the calculation of PFC emissions from aluminium production (Tier 2 method)

Technology[a]	Slope Coefficient[b, c] [(kg $_{PFC}$/t_{Al}) / (AE-Mins/cell-day)]		Overvoltage Coefficient[b, c, d] [(kg $_{CF4}$/t_{Al}) / (mV)]		Weight Fraction C_2F_6 / CF_4	
	CF_4	Uncertainty (+/-%)	CF_4	Uncertainty (+/-%)	C_2F_6/CF_4	Uncertainty (+/-%)
CWPB	0.143	6	1.16	24	0.121	11
SWPB	0.272	15	3.65	43	0.252	23
VSS	0.092	17	NR	NR	0.053	15
HSS	0.099	44	NR	NR	0.085	48

2C3. Aluminium production – PFCs Emissions – Slope vs Overvoltage method

Equation 4.26
PFC emissions by Slope method (Tier 2 and Tier 3 methods)

$$E_{CF4} = S_{CF4} \bullet AEM \bullet MP$$

and

$$E_{C2F6} = E_{CF4} \bullet F_{C2F6/CF4}$$

- E_{CF4} = emissions of CF_4 from aluminium production, kg CF_4
- E_{C2F6} = emissions of C_2F_6 from aluminium production, kg C_2F_6
- S_{CF4} = slope coefficient for CF_4, (kg CF_4/tonne Al)/(AE-Mins/cell-day)
- AEM = anode effect minutes per cell-day, AE-Mins/cell-day
- MP = metal production, tonnes Al
- $F_{C2F6/CF4}$ = weight fraction of C_2F_6/CF_4, kg C_2F_6/kg CF_4

Equation 4.27
PFC emissions by Overvoltage method (Tier 2 and Tier 3 methods)

$$E_{CF4} = OVC \bullet \frac{AEO}{CE/100} \bullet MP$$

and

$$E_{C2F6} = E_{CF4} \bullet F_{C2F6/CF4}$$

- E_{CF4} = emissions of CF_4 from aluminium production, kg CF_4
- E_{C2F6} = emissions of C2F6 from aluminium production, kg C_2F_6
- OVC = Overvoltage coefficient for CF_4, (kg CF_4/tonne Al)/mV
- AEO = anode effect overvoltage, mV
- CE = aluminium production process current efficiency expressed, percent (e.g., 95 percent)
- MP = metal production, tonnes Al
- $F_{C2F6/CF4}$ = weight fraction of C_2F_6/CF_4, kg C_2F_6/kg CF_4

2C3 Aluminium Production – PFC

Tier applied: T1
Key Category: Yes

Equation 4.25
PFC emissions (Tier 1 method)

$$E_{CF4} = \sum_i \left(EF_{CF4,i} \bullet MP_i\right)$$
and
$$E_{C2F6} = \sum_i \left(EF_{C2F6,i} \bullet MP_i\right)$$

Where:

E_{CF4} = emissions of CF_4 from aluminium production, kg CF_4

E_{C2F6} = emissions of C_2F_6 from aluminium production, kg C_2F_6

$EF_{CF4,i}$ = default emission factor by cell technology type *i* for CF_4, kg CF_4/tonne Al

$EF_{C2F6,i}$ = default emission factor by cell technology type *i* for C_2F_6, kg C_2F_6/tonne Al

MP_i = metal production by cell technology type *i*, tonnes Al

Equation 4.26
PFC emissions by slope method (Tier 2 and Tier 3 methods)

$$E_{CF4} = S_{CF4} \bullet AEM \bullet MP$$
and
$$E_{C2F6} = E_{CF4} \bullet F_{C2F6/CF4}$$

Where:

E_{CF4} = emissions of CF_4 from aluminium production, kg CF_4

E_{C2F6} = emissions of C_2F_6 from aluminium production, kg C_2F_6

S_{CF4} = slope coefficient for CF_4, (kg CF_4/tonne Al)/(AE-Mins/cell-day)

AEM = anode effect minutes per cell-day, AE-Mins/cell-day

MP = metal production, tonnes Al

$F_{C2F6/CF4}$ = weight fraction of C_2F_6/CF_4, kg C_2F_6/kg CF_4

Equation 4.27
PFC emissions by overvoltage method (Tier 2 and Tier 3 methods)

$$E_{CF4} = OVC \bullet \frac{AEO}{CE/100} \bullet MP$$
and
$$E_{C2F6} = E_{CF4} \bullet F_{C2F6/CF4}$$

Where:

E_{CF4} = emissions of CF_4 from aluminium production, kg CF_4

E_{C2F6} = emissions of C_2F_6 from aluminium production, kg C_2F_6

OVC = Overvoltage coefficient for CF_4, (kg CF_4/tonne Al)/mV

AEO = anode effect overvoltage, mV

CE = aluminium production process current efficiency expressed, percent (e.g., 95 percent)

MP = metal production, tonnes Al

$F_{C2F6/CF4}$ = weight fraction of C_2F_6/CF_4, kg C_2F_6/kg CF_4

Data needed
Optional data

	T1 Method	T2 Method
Activity Data	• **Primary aluminium production statistics**	• **Annual national production by smelter** • **Anode Effect minutes per cell-day** **or** • **Anode Effect Overvoltage**
EF and parameters	• Technology-based default emission factors for the main production technology types (CWPB, SWPB, VSS and HSS)	• Default technology specific co-efficients • *Technology specific emission coefficients linked to anode effect performance*

2B9 HCFC-22 Production– HFC-23

Tier applied: T1/T2
Key Category: no

Data needed
Optional data

	T1 Method	T2 Method
Activity Data	• **HCFC-22 production data**	• **Plant specific production data** • **Plant specific expected production data** • *Vent treatment data*
EF and parameters	• Default EF	• Default factors

2.D: Non-Energy Products from Fuels and Solvent Use

- Emissions from the use of fossil fuels as a product for primary purposes other than:
  - combustion for energy purposes
  - use as feedstock or reducing agent
  - incineration of waste oils/lubricants with/without energy recovery (Energy/Waste Sector).
- A small proportion of non-energy products oxidises during use
- Focus on direct CO_2 emissions and substantial NMVOC/CO emissions which eventually oxidise to CO_2 in the atmosphere

Types of fuels used	Examples of non-energy uses	CO_2	NMVOC, CO
Lubricants	Lubricants used in transportation and industry	X	
Paraffin waxes	Candles, corrugated boxes, paper coating, board sizing, adhesives, food production, packaging	X	
Bitumen; road oil and other petroleum diluents	Used in asphalt production for road paving		X
White spirit, kerosene, some aromatics	As solvent e.g. for surface coating (paint), dry cleaning		X

Calculating CO_2 emissions from non-energy product uses

Mass of oxidized carbon calculated separately for each non-energy use of fuel:

$$\sum \left(\text{Non-energy use of fuel} \times \text{Carbon content} \times \text{ODU factor} \right) \times {}^{44}/_{12} = CO_2 \text{ Emissions}$$

Quality control Approaches in IPPU

Carbonate balance

Top down assessment: Consumption (by type) = Imports − Exports + Production − Stocks

Compare

Bottom-up assessment: Consumption (by type) = Consumption under 2A Mineral Industry + Consumption under 2C Metal Industry + Consumption under 3C2 Liming (Agriculture)

NEU: Feedstock Balance Check

Compare

- the supply of feedstock/reductants as reported in national fuel statistics
- with the requirements for the feedstocks by each of the processes using them

Table 1.2
Types of use and examples of fuels used for non-energy applications

Type of use	Example of fuel types	Product/process	Chapter
Feedstock	natural gas, oils, coal	ammonia	3.2
	naphtha, natural gas, ethane, propane, butane, gas oil, fuel oils	methanol, olefins (ethylene, propylene), carbon black	3.9
Reductant	petroleum coke	carbides	3.6
	coal, petroleum coke	titanium dioxide	3.7
	metallurgical cokes, pulverised coal, natural gas	iron and steel (primary)	4.2
	metallurgical cokes	ferroalloys	4.3
	petroleum coke, pitch (anodes)	aluminium [1]	4.4
	metallurgical coke, coal	lead	4.6
	metallurgical coke, coal	zinc	4.7
Non-energy product	lubricants	lubricating properties	5.2
	paraffin waxes	misc. (e.g., candles, coating)	5.3
	bitumen (asphalt)	road paving and roofing	5.4
	white spirit[2], some aromatics	as solvent (paint, dry cleaning)	5.5

[1] Also used in secondary steel production (in electric arc furnaces) (see Chapter 4.2).
[2] Also known as mineral turpentine, petroleum spirits, industrial spirit ('SBP').

NEU: CO_2 Completeness Check

Comparison of reported CO_2 emissions with potential CO_2 emissions from the fuel for non-energy uses by

1. Calculating CO_2-equivalent carbon contents for the non-energy use of fossil fuels as reported in national energy statistics

2. Relating total CO_2 emissions reported per IPPU subcategory to (main) fuels used for non-energy purposes.

3. Comparing total reported fossil IPPU CO_2 emissions with a top-down estimate of potential CO_2 of the carbon content of the feedstocks used

Table 1.3 Verification of completeness of reported CO_2 from non-energy use of

NOTES						Solids				
1	Year:_________				Unit	Coal	Coke	Coal tars	Coal oils	Bl
2	A: Declared NEU (from commodity balance)				TJ					
3	B: Carbon Content				kg C/GJ					
	C: Total supplied for feedstock/non-energy	[C = A * B / 1000]			Gg C					
4	**D: Total supplied for feedstock/non-energy**	**[D = C * 44/12]**			Gg CO_2-eq.					
5	**E: Implied carbon fraction oxidised**	**[E = F / D * 100]**			%					
		Activity a)	CO_2 Emissions a)	IEF CO_2						
6	**F: Total fossil IPPU CO_2 reported**				Gg CO_2					
	2 INDUSTRIAL PROCESSES				Gg CO_2					
7	**2A: Mineral Industry**				Gg CO_2					
	(Please specify the subcategory.)				Gg CO_2					
7	**2B: Chemical Industry**				Gg CO_2					
	2B1: Ammonia Production				Gg CO_2					
	2B5: Carbide Production				Gg CO_2					
	2B6: Titanium Dioxide Production				Gg CO_2					
	2B8: Petrochemical and Carbon Black Production				Gg CO_2					
	2B8a: Methanol				Gg CO_2					
	2B8b: Ethylene				Gg CO_2					
	2B8f: Carbon Black				Gg CO_2					
	2B10: Other				Gg CO_2					
7	**2C: Metal Industry**				Gg CO_2					
	2C1: Iron and Steel Production				Gg CO_2					
	2C2: Ferroalloys Production				Gg CO_2					
	2C3: Aluminium Production				Gg CO_2					
	2C5: Lead Production				Gg CO_2					
	2C6: Zinc Production				Gg CO_2					
	2C7: Other				Gg CO_2					
7	**2D: Non-Energy Products from Fuels and Solvent Use**				Gg CO_2					
	2D1: Lubricant Use				Gg CO_2					
	2D2: Paraffin Wax Use				Gg CO_2					
	2D3: Solvent Use				Gg CO_2					
	2D4: Other				Gg CO_2					
7	**2H: Other**				Gg CO_2					
	2H1: Pulp and Paper Industry				Gg CO_2					
	2H2: Food and Beverage Industry				Gg CO_2					
	2F3: Other				Gg CO_2					
	EXCEPTIONS REPORTED ELSEWHERE				Gg CO_2					
7	**1A FUEL COMBUSTION ACTIVITIES**				Gg CO_2					
	1A1a: Main Activity Electricity and Heat Production				Gg CO_2					
	1A1b: Petroleum Refining				Gg CO_2					
	1A1c: Manufacture of Solid Fuels and Other Energy Industries				Gg CO_2					
	1A2: Manufacturing Industries and Construction				Gg CO_2					

a) Same Activity Data and emissions as in sectoral background table (also for Activity Data NE, NO, C, and for emissions NE, NO, IE, where applicable).
b) To be included only if coke production is reported as part of integrated iron and steel production.
1: To be specified per year
2: Cf. Auxiliary worksheet for CO2-Reference Approach to subtract the NEU from total apparent consumption
3: IPCC default or country-specific values
4: So-called potential emissions, i.e., carbon embodied in the feedstock/non-energy fuels expressed in CO_2-eq.
5: Ratio of CO_2 emissions (direct emissions reported as well as atmospheric inputs of CO_2 from other carbon (non-CO_2)) at some aggregation level (by detailed fuel type or by major fuel type) to total
6: Sum of subcategories below including IPPU sources allocated to Fuel Combustion Activities 1A (due to transfer of by-product fuels to another source category (and 1B, 4C when appropriate))
7: Sum of subcategories of that category

2006 IPCC Guidelines for National Greenhouse Gas Inventories

Session 3: Electronics Industry (2.E) and ODS substitutes (2.F)

Electronic Industry Emissions

Electronics Industry

This section includes methods to quantify GHG emission from manufacturing of

- semiconductors
- thin-film-transistor flat panel displays
- photovoltaic elements

and use of heat transfer fluids

Common estimation approaches (2E1–2E3)

Separate estimation approach (2E4)

Code	Category
2E1:	Integrated Circuit or Semiconductor
2E2:	TFT Flat Panel Display
2E3:	Photovoltaics
2E4:	Heat Transfer Fluid
2E5:	Other

GHGs are emitted during the use of fluorinated compounds (FC) for

- plasma etching intricate patterns
- cleaning reactor chambers
- temperature control

Among others, emissions vary according to

- the **gases used** in manufacturing different types of electronic devices
- the **process used**
- the **implementation of emission reduction** technology

Gases: CF_4, C_2F_6, C_3F_8, c-C_4F_8, c-C_4F_8O, C_4F_6, C_5F_8, CHF_3, CH_2F_2, nitrogen trifluoride (NF_3), sulfur hexafluoride (SF_6)

2E1-2E3 - Tier 1

To calculate emissions from etching and CVD cleaning for semiconductors or liquid crystal displays based on production output:

For each class of products, and each gas:

Production Capacity + **Used capacity** + **Emission factor** = **FC emission**

2E1-2E3 Tier 2

Process-gas specific

Equation 6.2
Tier 2a method for estimation of FC emissions

$$E_i = (1-h) \bullet FC_i \bullet (1-U_i) \bullet (1-a_i \bullet d_i)$$

Where:
E_i = emissions of gas *i*, kg
FC_i = consumption of gas *i*,(e.g., CF_4, C_2F_6, C_3F_8, c-C_4F_8, c-C_4F_8O, C_4F_6, C_5F_8, CHF_3, CH_2F_2, NF_3, SF_6),
kg
h = fraction of gas remaining in shipping container (heel) after use, fraction
U_i = use rate of gas *i* (fraction destroyed or transformed in process), fraction
a_i = fraction of gas *i* volume used in processes with emission control technologies (company- or plantspecific),
fraction
d_i = fraction of gas *i* destroyed by the emission control technology, fraction

In addition: Calculation of by-product emissions of CF_4, C_2F_6, CF_3, C_3F_8

Process-type specific

Equation 6.7
Tier 2b method for estimation of FC emissions

$$E_i = (1-h) \bullet \sum_p \left[FC_{i,p} \bullet (1-U_{i,p}) \bullet (1-a_{i,p} \bullet d_{i,p})\right]$$

E_i = emissions of gas *i*, kg
p = process type (etching vs. CVD chamber cleaning)
$FC_{i,p}$ = mass of gas *i* fed into process type *p* (e.g., CF_4, C_2F_6, C_3F_8, c-C_4F_8, c-C_4F_8O, C_4F_6, C_5F_8, CHF_3, CH_2F_2, NF_3, SF_6), kg
h = fraction of gas remaining in shipping container (heel) after use, fraction
$U_{i,p}$ = use rate for each gas *i* and process type *p* (fraction destroyed or transformed), fraction
$a_{i,p}$ = fraction of gas *i* volume fed into process type *p* with emission control technologies (company-or
plant-specific), fraction
$d_{i,p}$ = fraction of gas *i* destroyed by the emission control technology used in process type *p* (If more than
one emission control technology is used in process type *p*, this is the average of the fraction
destroyed by those emission control technologies, where each fraction is weighted by the quantity of
gas fed into tools using that technology), fraction

Presentation on US-EPA Electronics Industry estimation approach (Stephanie Bogle)

Substitutes for ozone depleting substances

OVERVIEW I

- Mostly small and diffuse sources
- In some cases product function depends on GHG being contained (e.g. fridges, air conditioning)
- Emissions might occurr
  - during manufacture
  - and/or use
  - and/or decomissioning

  depending on source category

Code	Category	HFCs	PFCs
2F1:	Refrigeration and Air Conditioning	X	X
2F1a:	Refrigeration and Stationary Air Conditioning	X	X
2F1b:	Mobile Air Conditioning	X	X
2F2:	Foam Blowing Agents	X	X
2F3:	Fire Protection	X	X
2F4:	Aerosols	X	X
2F5:	Solvents	X	X
2F6:	Other Applications	X	X

OVERVIEW II

- ***Applications* or *Sub-applications*** - major groupings of current and expected usage of the ODS substitutes

- ***Actual emissions*** vs. ***Potential emissions*** (2006 vs.1996)

- ***Prompt emissions*** (within 2 years) **and Delayed emissions**

TABLE 7.2
OVERVIEW OF DATA REQUIREMENTS FOR DIFFERENT TIERS AND APPROACHES

	Approach A (emission-factor approach)	Approach B (mass-balance approach)
Tier 2 (emission estimation at a disaggregated level)	• Data on chemical sales and usage pattern by sub-application [country-specific or globally/regionally derived] • Emission factors by sub-application [country-specific or default]	• Data on chemical sales by sub-application [country-specific or globally/regionally derived] • Data on historic and current equipment sales adjusted for import/export by sub-application [country-specific or globally/regionally derived]
Tier 1 (emission estimation at an aggregated level)	• Data on chemical sales by application [country-specific or globally/regionally derived] • Emission factors by application [country-specific or (composite) default]	• Data on chemical sales by application [country-specific or globally/regionally derived] • Data on historic and current equipment sales adjusted for import/export by application [country-specific or globally/regionally derived]

CHEMICALS AND APPLICATIONS

Chemical	Refrigeration and Air Conditioning	Fire Suppression and Explosion Protection	Aerosols		Solvent Cleaning	Foam Blowing	Other Applications
			Propellants	Solvents			
HFC-23	X	X					
HFC-32	X						
HFC-125	X	X					
HFC-134a	X	X	X			X	X
HFC-143a	X						
HFC-152a	X		X			X	
HFC-227ea	X	X	X			X	X
HFC-236fa	X	X					
HFC-245fa				X		X	
HFC-365mfc				X	X	X	
HFC-43-10mee				X	X		
PFC-14 (CF4)		X					
PFC-116 (C2F6)							X
PFC-218 (C3F8)							
PFC-31-10 (C4F10)		X					
PFC-51-14 (C6F14)					X		
BLENDS							

BLENDS

Blend	Constituents	Composition (%)
R-400	CFC-12/CFC-114	Should be specified[1]
R-401A	HCFC-22/HFC-152a/HCFC-124	(53.0/13.0/34.0)
R-401B	HCFC-22/HFC-152a/HCFC-124	(61.0/11.0/28.0)
R-401C	HCFC-22/HFC-152a/HCFC-124	(33.0/15.0/52.0)
R-402A	HFC-125/HC-290/HCFC-22	(60.0/2.0/38.0)
R-402B	HFC-125/HC-290/HCFC-22	(38.0/2.0/60.0)
R-403A	HC-290/HCFC-22/PFC-218	(5.0/75.0/20.0)
R-403B	HC-290/HCFC-22/PFC-218	(5.0/56.0/39.0)
R-404A	HFC-125/HFC-143a/HFC-134a	(44.0/52.0/4.0)
R-405A	HCFC-22/ HFC-152a/ HCFC-142b/PFC-318	(45.0/7.0/5.5/42.5)
R-406A	HCFC-22/HC-600a/HCFC-142b	(55.0/14.0/41.0)
R-407A	HFC-32/HFC-125/HFC-134a	(20.0/40.0/40.0)
R-407B	HFC-32/HFC-125/HFC-134a	(10.0/70.0/20.0)
R-407C	HFC-32/HFC-125/HFC-134a	(23.0/25.0/52.0)
R-407D	HFC-32/HFC-125/HFC-134a	(15.0/15.0/70.0)
R-407E	HFC-32/HFC-125/HFC-134a	(25.0/15.0/60.0)
R-408A	HFC-125/HFC-143a/HCFC-22	(7.0/46.0/47.0)
R-409A	HCFC-22/HCFC-124/HCFC-142b	(60.0/25.0/15.0)
R-409B	HCFC-22/HCFC-124/HCFC-142b	(65.0/25.0/10.0)
R-410A	HFC-32/HFC-125	(50.0/50.0)
R-410B	HFC-32/HFC-125	(45.0/55.0)
R-411A	HC-1270/HCFC-22/HFC-152a	(1.5/87.5/11.0)
R-411B	HC-1270/HCFC-22/HFC-152a	(3.0/94.0/3.0)
R-411C	HC-1270/HCFC-22/HFC-152a	(3.0/95.5/1.5)
R-412A	HCFC-22/PFC-218/HCFC-142b	(70.0/5.0/25.0)
R-413A	PFC-218/HFC-134a/HC-600a	(9.0/88.0/3.0)
R-414A	HCFC-22/HCFC-124/HC-600a/HCFC-142b	(51.0/28.5/4.0/16.5)
R-414B	HCFC-22/HCFC-124/HC-600a/HCFC-142b	(50.0/39.0/1.5/9.5)
R-415A	HCFC-22/HFC-152a	(82.0/18.0)
R-415B	HCFC-22/HFC-152a	(25.0/75.0)
R-416A	HFC-134a/HCFC-124/HC-600	(59.0/39.5/1.5)
R-417A	HFC-125/HFC-134a/HC-600	(46.6/50.0/3.4)
R-418A	HC-290/HCFC-22/HFC-152a	(1.5/96.0/2.5)
R-419A	HFC-125/HFC-134a/HE-E170	(77.0/19.0/4.0)
R-420A	HFC-134a/HCFC-142b	(88.0/12.0)
R-421A	HFC-125/HFC-134a	(58.0/42.0)
R-421B	HFC-125/HFC-134a	(85.0/15.0)
R-422A	HFC-125/HFC-134a/HC-600a	(85.1/11.5/3.4)
R-422B	HFC-125/HFC-134a/HC-600a	(55.0/42.0/3.0)
R-422C	HFC-125/HFC-134a/HC-600a	(82.0/15.0/3.0)
R-500	CFC-12/HFC-152a	(73.8/26.2)
R-501	HCFC-22/CFC-12	(75.0/25.0)
R-502	HCFC-22/CFC-115	(48.8/51.2)
R-503	HFC-23/CFC-13	(40.1/59.9)
R-504	HFC-32/CFC-115	(48.2/51.8)
R-505	CFC-12/HCFC-31	(78.0/22.0)
R-506	CFC-31/CFC-114	(55.1/44.9)
R-507A	HFC-125/HFC-143a	(50.0/50.0)
R-508A	HFC-23/PFC-116	(39.0/61.0)
R-508B	HFC-23/PFC-116	(46.0/54.0)
R-509A	HCFC-22/PFC-218	(44.0/56.0)

DATA REQUIRED BY THE CRTS I

TABLE 2(II) SECTORAL REPORT FOR INDUSTRIAL PROCESSES AND PRODUCT USE - EMISSIONS OF HFCs, PFCs, SF_6 AND NF_3
(Sheet 1 of 1)

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GREENHOUSE GAS SOURCE AND SINK CATEGORIES	HFC-23	HFC-32	HFC-41	HFC-43-10mee	HFC-125	HFC-134	HFC-134a	HFC-143	HFC-143a	HFC-152	HFC-152a	HFC-161	HFC-227ea	HFC-236cb	HFC-236ea	HFC-236fa	HFC-245ca	HFC-245fa	HFC-365mfc	Unspecified mix of HFCs [1]	Total HFCs	CF_4	C_2F_6	C_3F_8
	(t)																			CO_2 equivalents (kt) [2]				
2.F. Product uses as substitutes for ODS																								
2.F.1. Refrigeration and air conditioning																								
2.F.2. Foam blowing agents																								
2.F.3. Fire protection																								
2.F.4. Aerosols																								
2.F.5. Solvents																								
2.F.6. Other applications																								
2.G. Other product manufacture and use																								
2.G.1. Electrical equipment																								
2.G.2. SF_6 and PFCs from other product use																								
2.G.4. Other																								

(1) In accordance with the MPGs (chapter II), emissions of HFCs and PFCs should be reported for each relevant chemical. However, if it is not possible to report values for each chemical (i.e. owing to mixtures, confidential data, lac unspecified mix of HFCs; unspecified mix of PFCs; and/or unspecified mix of HFCs and PFCs. Note that the unit used in these columns is kt of carbon dioxide equivalent (CO_2 eq).
(2) See footnote 3 to table 2(I).
(3) The total actual emissions equal the sum of the actual emissions of each halocarbon, SF_6 and NF_3 for categories 2.C, 2.E, 2.F, 2.G and 2.H in this table multiplied by the corresponding GWP values.

Note: Minimum level of aggregation is needed to protect confidential business and military information, where it would identify particular entity's/entities' confidential data.

Documentation box:

- Parties should provide a detailed description of the industrial processes and product use sector in chapter 4 ("Industrial processes and product use" (CRT sector 2)) of the NID. Use this documentation box to provide references to re needed to explain the contents of this table.
- If estimates are reported under category 2.H. (Other), provide in this documentation box information on activities covered under this category and a reference to the section of the NID where background information can be found.

DATA REQUIRED BY THE CRTs II

TABLE 2(II).B-H SECTORAL BACKGROUND DATA FOR INDUSTRIAL PROCESSES AND PRODUCT USE
Sources of fluorinated substances
(Sheet 2 of 2)

Year
Submission
Country

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GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Gas *(please specify)* *One row per substance*	ACTIVITY DATA *Amount*			IMPLIED EMISSION FACTORS [1]			EMISSIONS [2]			RECOVERY [3,4]
		Filled into new manufactured products	In operating systems (average annual stocks)	Remaining in products at decommissioning	Product manufacturing factor	Product life factor	Disposal loss factor	From manufacturing	From stocks	From disposal	
		(t)			%			(t)			
2.F. Product uses as substitutes for ODS											
2.F.1. Refrigeration and air-conditioning											
2.F.1.a. Commercial refrigeration	e.g. HFC-134a, 365mfc, HFC-43-10mee										
2.F.1.b. Domestic refrigeration	e.g. HFC-134a										
2.F.1.c. Industrial refrigeration	e.g. HFC-152a										
2.F.1.d. Transport refrigeration	e.g. HFC-125										
2.F.1.e. Mobile air-conditioning	e.g. HFC-143a										
2.F.1.f. Stationary air-conditioning	e.g. HFC-32										
2.F.2. Foam blowing agents	e.g. HFC-23										
2.F.2.a. Closed cells	e.g. HFC-236fa										
2.F.2.b. Open cells	e.g. HFC-245fa										
2.F.3. Fire protection	e.g. HFC-227ea										
2.F.4. Aerosols											
2.F.4.a. Metered dose inhalers											
2.F.4.b. Other *(please specify - one row per substance)*											
2.F.5. Solvents	e.g. SF_6 and PFCs										
2.F.6. Other applications [10]											
2.F.6.a. Emissive											
2.F.6.b. Contained											
2.G. Other product manufacture and use											

Disaggregation of chemical data across an application

2.F. Product uses as substitutes for ODS
2.F.1. Refrigeration and air-conditioning

- 2.F.1.a. Commercial refrigeration
- 2.F.1.b. Domestic refrigeration
- 2.F.1.c. Industrial refrigeration
- 2.F.1.d. Transport refrigeration
- 2.F.1.e. Mobile air-conditioning
- 2.F.1.f. Stationary air-conditioning

2.F.2. Foam blowing agents

- 2.F.2.a. Closed cells
- 2.F.2.b. Open cells

2.F.3. Fire protection

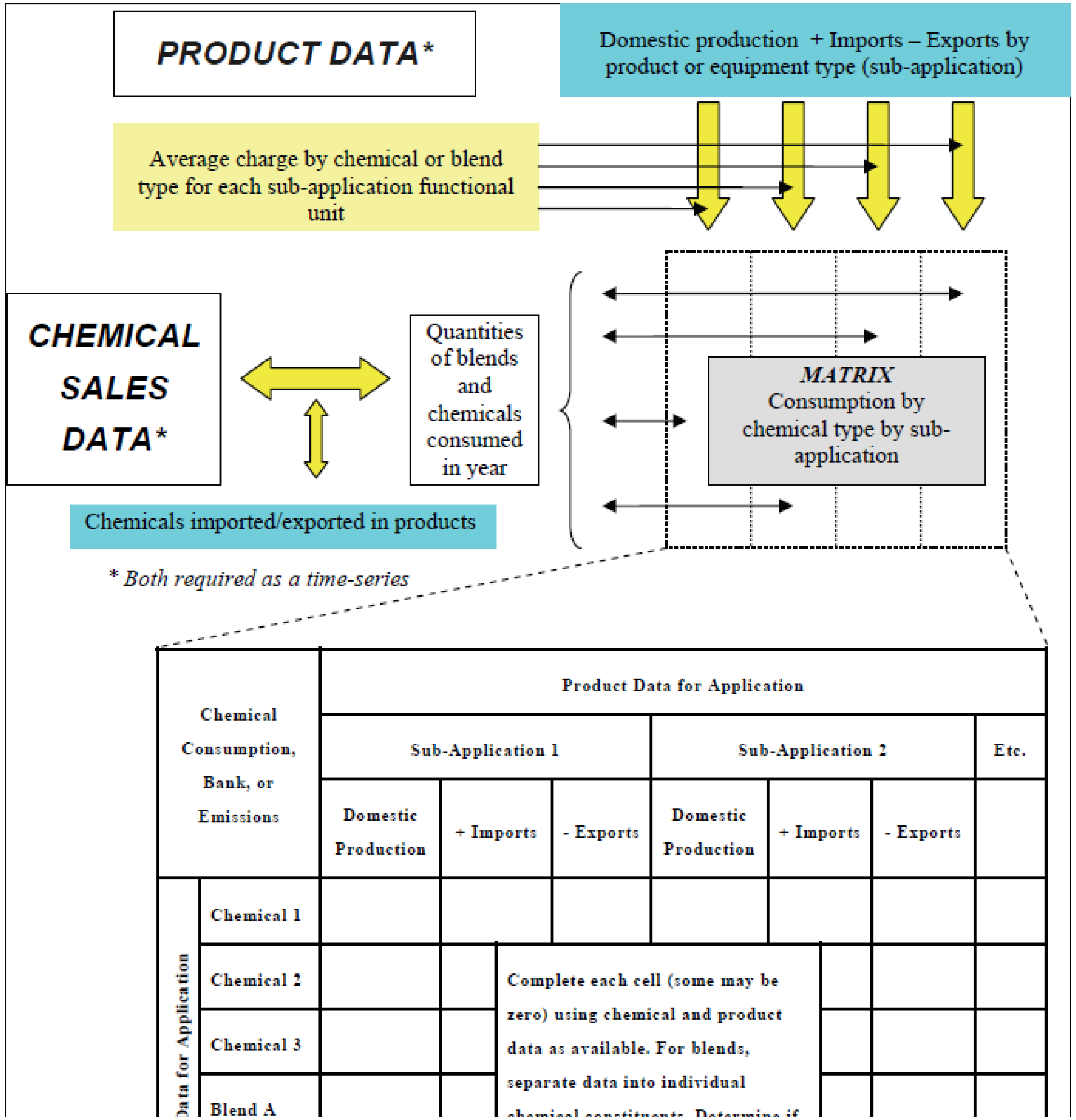
2.F.4. Aerosols

- 2.F.4.a. Metered dose inhalers
- 2.F.4.b. Other (please specify - one row per substance)

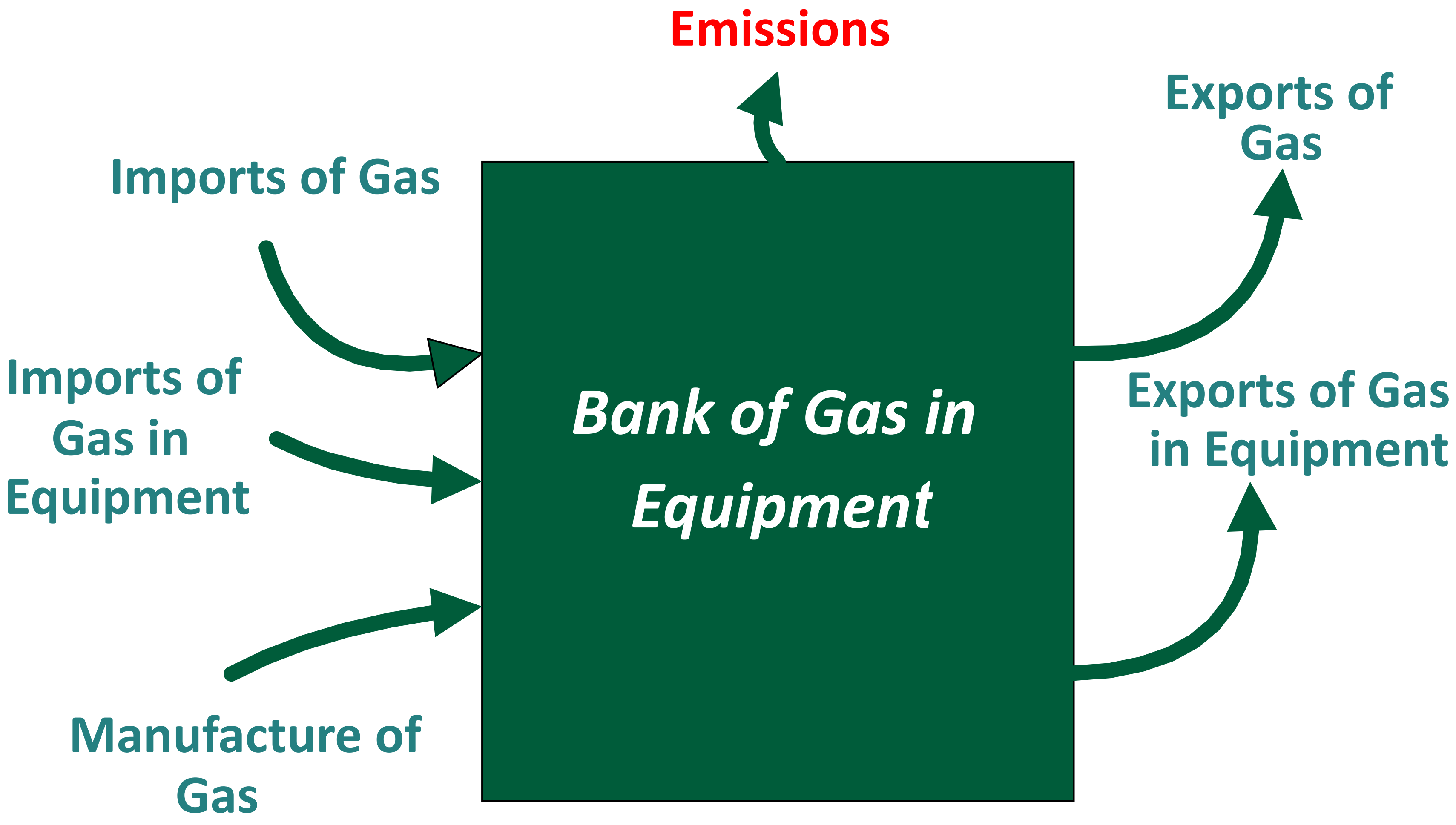
2.F.5. Solvents

2.F.6. Other applications [10]

- 2.F.6.a. Emissive
- 2.F.6.b. Contained

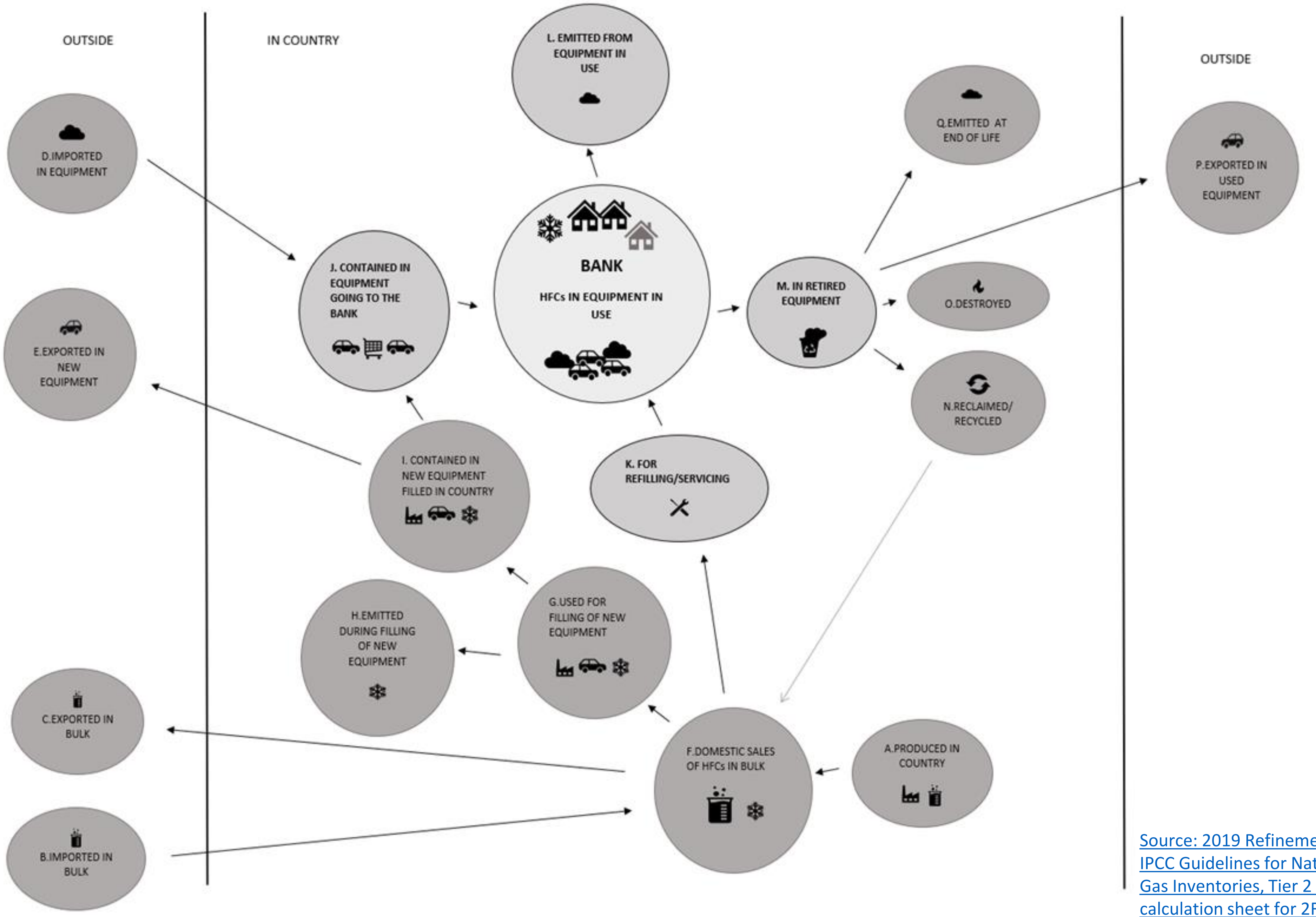


Bank I



Emissions
Imports of Gas
Exports of Gas
Imports of Gas in Equipment
Bank of Gas in Equipment
Exports of Gas in Equipment
Manufacture of Gas

Bank II



[Source: 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Tier 2 Example calculation sheet for 2F1]

MASS BALANCE APPROACH

- A mass balance approach can be used, e.g. for cooling/air conditioning, certain foams, fire protection, electrical equipment
- The mass balance approach
  - tracks the amount of new chemical introduced each year
  - accounting for gas that is used to fill new equipment capacity or to replayce destroyed gas
  - Consumption which cannot be accounted for is assumed to be emitted/replace emitted gas

EQUATION 7.3

GENERAL MASS BALANCE EQUATION FOR TIER 1b

$$Emissions = Annual\ Sales\ of\ New\ Chemical - (Total\ Charge\ of\ New\ Equipment - Original\ Total\ Charge\ of\ Retiring\ Equipment)$$

Modelling Emissions

- The source categories suitable for the mass balance approach tend to have a long lifetime during which they emit small amounts continuously.
- Modelling allows understanding how the banked amounts of a GHG (e.g. R-134a as coolant) develop over time as new equipment is bought and old equipment is discarded.
- Start simple – e.g. using MS Excel - and improve over time,
- Adjust the model regularly based on studies/statistics.

Data collection for ODS Substitutes

- Data often not readily available
  - Industry often not aware of reporting needs
  - No / few statistics
  - High effort of data collection for large number of small sources
- Quality issues due to need for many assumptions
- Available data often not in the correct level of disaggregation, e.g. data available by chemical, but not by application
- Reporting of HFCs under the Montreal Protocol can be a key source of data, but focuses on consumption per chemical
- Start simple and build over time
  - Start with the typically most relevant applications/sub-applications and chemicals, e.g. HFC-134a in domestic and commercial refrigeration, mobile and stationary air conditioning. Extend scope over time
  - Start with simple assumptions, refine over time
  - Tap into existing reporting structures (e.g. Montreal Protocol) and assess options to refine data collection to suit both needs

2F1: Refrigeration / Air Conditioning

Tier 2b *(Mass-Balance):*

Emissions = Annual Sales of New Refrigerant – Total Charge of New Equipment+

+ Original Total Charge of Retiring Equipment - Amount of Intentional Destruction

in estimating Annual Sales of New Refrigerant, Total Charge of New Equipment, and Original Total Charge of Retiring Equipment, inventory compilers should account for imports and exports of both chemicals and equipment.

Tier 2a *(Emission factor):*

Emissions = Econtainers + Echarge + Elifetime + Eend-of-life

- **Econtainers = RM* c/100**
- **Echarge = M * k/100**
- **Elifetime = B *x/100**
- **Eend-of-life = M * p/100 * (1- n/100)**

EFs: c, k, x, p, n

IPPU Activity Data: Data Collection – RAC

Which data to collect

- schedule of phase out for charging of brand-new equipment and for servicing
- number of equipment disposed of for each type of application
- all virgin refrigerants sold for charging new equipment and for servicing in the different sectors
- equipment produced on a national level using HFC refrigerants (for all sub-applications)
- number of equipment using HFCs (imported and exported)
- HFC refrigerants recovered for re-processing or for destruction
- average equipment lifetime
- initial charge of systems

Where to find it

- Regulation for phase-out of CFCs and HCFCs
- Government Statistics
- Refrigerant Manufacturers and Distributors
- Disposal Companies
- Import/Export Companies
- Manufacturer Association
- Marketing Studies

2F2: Foams Blowing Agents

<u>Open foams</u> *(GHG immediate release):*

GHG Emissions = Mt

Mt - *total HFC used in manufacturing new open-cell foam in year t, tonnes*

<u>Closed foams</u> (*GHG delayed release):*

GHG Emissions = Mt*EFFYL+ Bankt*EFAL + DLt – RDt

Mt - *total HFC used in manufacturing new closed-cell foam in year t*
EFFYL - *first year loss emission factor*
Bankt - *HFC charge blown into closed-cell foam manufacturing between year t and year t-n*
EFAL - *annual loss emission factor*
DLt - *decommissioning losses or remaining losses of chemical at the end of*
RDt - *HFC emissions prevented by recovery and destruction*

2F4 / 2F5: Solvents / Aerosols

For prompt emissions *(solvents, aerosols):*

GHG Emissions = St*EF + St-1*(1-EF)

S *– quantity of chemical sales in current and previous year t, t-1*

EF *= 1 for two years (100%), default EF - 0.5/0.5*

TOOLS HELPING WITH ESTIMATION OF ODS SUBSTITUTE EMISSIONS

- IPCC 2006 GL worksheets
- IPCC 2006 GL Calculation Examples for 2F1, 2F2, 2F3, IPCC 2019 Refinement Calculation Examples for 2F1
- Draft HFC Tool under development by US EPA – first estimations of HFC emissions based on Montreal Protocol reporting

Live demo of draft HFC-Tool

Tier 1 Refrigeration
Argentina - HFC-143a

HFC−143a

Current Year	2005

Use in current year - 2005 (tonnes)	**Data Used Here**
Production of HFC-143a	800
Imports in current Year	200
Exports in current year	0
Total new agent to domestic market	*1000*

Year of Introduction of HFC-143a	1998
Growth Rate in New Equipment Sales	3.0%

Tier 1 Defaults	
Assumed Equipment Lifetime (years)	15
Emission Factor from installed base	15%
% of HFC-143a destroyed at End-of-Life	0%

Example 1. In Country X the production of a specific refrigerant (HFC-143a) is 800 tonnes with an additional 200 tonnes in imported equipment, making a total consumption of 1,000 tonnes in 2005.

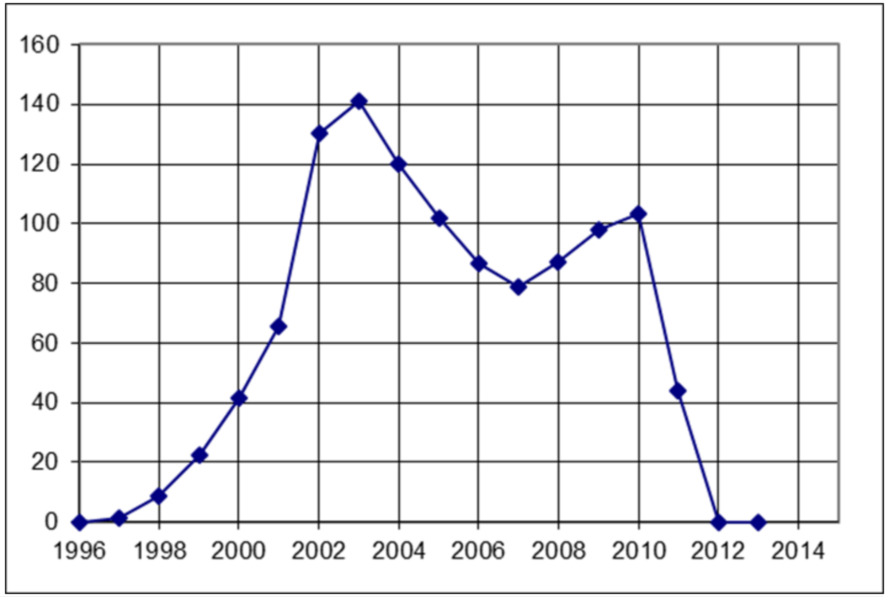
Based on the consumption pattern and knowledge of the year of introduction of the refrigerant (1998), it can be estimated that emissions will be 461 tonnes assuming the development of banks over the previous seven years.

The bank in 2005 is estimated at 3,071 tonnes.

Estimated data for earlier years	1996	1997	1998	1999	2000	2001	2002	2003	2004	**2005**
Production	0	0	81	167	259	355	458	566	680	**800**
Agent in Exports	0	0	0	0	0	0	0	0	0	**0**
Agent in Imports	0	0	20	42	65	89	114	141	170	**200**
Total New Agent in Domestic Equipment	0	0	102	209	323	444	572	707	850	**1000**
Agent in Retired Equipment	0	0	0	0	0	0	0	0	0	**0**
Destruction of agent in retired equipment	0	0	0	0	0	0	0	0	0	**0**
Release of agent from retired equipment	0	0	0	0	0	0	0	0	0	**0**
Bank	0	0	102	296	575	933	1365	1867	2437	**3071**
Emission	0	0	15	44	86	140	205	280	365	**461**

Example 2. Country X imported only the refrigerant HFC-134a in years 1997-2003 (there is no production and export). Based on the consumption pattern, it can be estimated that in 2013 there were no GHG emissions taking into account development of the bank and emissions from retired equipment

Current Year	**2013**
Use in current year - 2013 (tonnes)	
Production of HFC-134a	0
Imports in current Year	0
Exports in current year	0
Total new agent to domestic market	**0**
Year of Introduction of HFC-134a	**1997**
Growth Rate in New Equipment Sales, %	2.5
Tier 1 Defaults	
Assumed Equipment Lifetime (years)	10
Emission Factor from installed base, %	15
% of HFC-134a destroyed at End-of-Life	25



Estimated data for earlier years	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Production																		
Agent in Exports																		
Agent in Imports	0	10	50	100	150	200	500	200										
Total New Agent in Domestic Equipment	0	10	50	100	150	200	500	200										0
Agent in Retired Equipment												9	43	85	124	59	0	0
Destruction of agent in retired equipment												2	11	21	31	15		
Release of agent from retired equipment												6	32	64	93	44		
Bank	0	10	59	150	277	436	870	940	799	679	577	482	367	227	69	0	0	0
Emissions	0	**2**	**9**	**22**	**42**	**65**	**131**	**141**	**120**	**102**	**87**	**79**	**87**	**98**	**103**	**44**	0	0

2G: Other Product Manufacture and Use

Code	Category	Code	Category
2G1	Electrical Equipment	2G2c	Other
2G1a	Manufacture	2G3	N_2O from Product Uses
2G1b	Use	2G3a	Medical Applications
2G1c	Disposal	2G3b	Propellant for Pressure
2G2	SF_6/PFCs from Other Uses	2G3c	Other
2G2a	Military Applications	2G4	Other
2G2b	Accelerators		

SF_6 and PFCs: electrical equipment: gas insulated switchgear and substations (GIS), gas circuit breakers (GCB), high voltage gas-insulated lines (GIL), gas-insulated power transformers (GIT). **Military equipment:** ground and airborne radar, avionics, missile guidance systems, ECM (Electronic Counter Measures), sonar, amphibious assault vehicles, other surveillance aircraft, lasers, SDI (Strategic Defence Initiative), stealth aircraft. PFCs for cooling electric motors, e.g., in ships and submarines. **Cosmetic and medical applications, research particle accelerators.**

N_2O: Medical applications, Auto-racing, Propellant in aerosol products

Discussion

- How to start estimating ODS substitutes emissions?
  - Which (sub)-applications and chemicals to focus on?
  - Which data sources to consider?
  - Which tools to use?

- How to start estimating emissions from electronics prouction?
  - Which categories are likely most relevant?
  - Which data sources to consider?

Thank you