SUPPORTING INFORMATION FOR:

Ciacci, L., T.T. Werner, I. Vassura, and F. Passarini. 2018. Backlighting the European indium recycling potentials. *Journal of Industrial Ecology.*

Summary

This supporting information includes information on indium refinery production capacity in Europe (Table S1), extra-EU import and export of unwrought indium and indium powders (Table S2 and Table S3, respectively), first-use and end-use market shares of indium in the EU-28 (Table S4), ranges of indium content in selected end-use products (Table S5), correspondence between finished goods and UNU-KEYS for conversion from product weight to indium content (Table S6), average indium contents and relative standard deviation applied in the study (Table S7), lifetime statistics by end-use application of indium (Table S8), life cycle inventory of indium recovery from end-of-life liquid crystal displays (LCD) (Table S9), uncertainty analysis results (Figure S1), and comparison between the indium cumulative in-use stock (IUS) and the output from use estimated by major application segment of indium (Figure S2).

Table S1. Indium refinery production capacity in Europe (Brown et al. 2016; Survey 2017). Values are in tonnes of indium.

Year	Belgium	France	Germany	Italy	Netherlands	United Kingdom
2002	40	65	10	5	5	5
2003	40	10	10	5	5	5
2004	30	10	10	5	5	5
2005	30	10	9	5	5	5
2006	30	10	10	5	5	5
2007	30	10	10	5	5	5
2008	30	0	10	5	5	5
2009	30	0	10	5	5	5
2010	30	0	10	5	5	5
2011	30	0	10	5	5	5
2012	30	13	10	5	5	5
2013	30	33	10	5	5	5
2014	30	48	10	5	5	5
2015	20	41	NA	NA	NA	NA

NA = Not available

Table S2. Extra-EU import of unwrought indium and indium powders (Eurostat 2017). Values are in tonnes of indium.

Country	2012	2013	2014
Belgium	2	1	2
France	0	0	0
Germany	8	7	14
Italy	2	3	2
Netherlands	6	4	1
United Kingdom	47	45	43
Total extra-EU import	**65**	**60**	**62**

Table S3. Extra-EU export of unwrought indium and indium powders (Eurostat 2017). Values are in tonnes of indium.

Country	2012	2013	2014
Belgium	9	21	12
France	9	21	30
Germany	6	2	1
Italy	<1	<1	<1
Netherlands	<1	1	<1
United Kingdom	43	28	23
Total extra-EU export	**68**	**73**	**66**

Table S4. First-use and end-use market shares of indium in the EU-28 (Mikolajczak 2017).

	Glass coating	Metallurgy	Electrical and semiconductors	Research and other uses
First-uses	10%	30%	40%	20%
End-uses	66%	13%	19%	3%

Table S5. Ranges of indium content in selected end-use products.

Application	In content	Reference
Laptops; tablets; mobile phones; smartphones; LCD/LED monitors; LCD/LED TVs; indicator panels; cameras and other application incorporating flat panel displays	10-100 ppm	(Buchert et al. 2012; Cucchiella et al. 2015; Nakajima et al. 2008; Takahashi et al. 2009; Chancerel et al. 2013; Rocchetti et al. 2016; Chang et al. 2015)
Motor cars and other motor vehicles	0.2-1.6 ppb	(Cullbrand and Magnusson 2011; Widmer et al. 2015)
Photosensitive semiconductor devices, including solar cells	100-500 ppb	(Andersson 2000; Solar Frontier K. K. 2016)
Alkaline batteries	1-100 ppb	Own assumption based on (Werner 2017)
Research and other uses	0.1-50 ppb	Own assumption based on (Werner 2017)

Table S6. Correspondence between finished goods and UNU-KEYS (Baldè et al. 2016) for conversion from product weight to indium content.

Description	UNU-KEYS
Laptop PCs and palm-top organisers	303
Telephones for cellular networks or for other wireless networks	306
Flat panel video monitor, LCD or plasma, etc., without tuner (colour video monitors) (excluding with cathode-ray tube)	309
Monitors and projectors, principally used in an automatic data processing system	308
Colour video monitors with cathode-ray tube	407
Indicator panels incorporating liquid crystal display (LCD)	309
Indicator panels incorporating light emitting diodes (LED)	309
Digital cameras	406
Portable receivers for calling or paging	402
Radio broadcast receivers (except for cars), capable of operating without an external source of power	402
Radio broadcast receivers for motor vehicles with sound recording or reproducing apparatus	402
Radio broadcast receivers for motor vehicles, n.e.c.	402
Video camera recorders	406
Other television receivers, whether or not combined with radio-broadcast receivers or sound or video recording or reproduction apparatus n.e.c.	408

Table S7. Average indium contents and relative standard deviation (RSD) applied in the study. NACE Rev.2 codes were used except otherwise specified.

End-use market	Rev.2 Code	Description	Average In content (% w/w)	RSD
Glass coating	26201100	Laptop PCs and palm-top organisers	0,006%	27%
Glass coating	26302200	Telephones for cellular networks or for other wireless networks	0,006%	27%
Glass coating	26302330	Telephone sets (excluding line telephone sets with cordless handsets and telephones for cellular networks or for other wireless networks); videophones	0,006%	27%
Glass coating	26403460	Flat panel video monitor, LCD or plasma, etc., without tuner (colour video monitors) (excluding with cathode-ray tube)	0,006%	27%
Glass coating	26201700	Monitors and projectors, principally used in an automatic data processing system	0,006%	27%
Glass coating	26402090	Other television receivers, whether or not combined with radio-broadcast receivers or sound or video recording or reproduction apparatus n.e.c.	0,006%	27%
Glass coating	27902020	Indicator panels incorporating liquid crystal display (LCD)	0,006%	27%
Glass coating	27902050	Indicator panels incorporating light emitting diodes (LED)	0,006%	27%
Glass coating	26701300	Digital cameras	0,006%	27%
Glass coating	26302340	Portable receivers for calling or paging	0,006%	27%
Glass coating	26401100	Radio broadcast receivers (except for cars), capable of operating without an external source of power	0,006%	27%
Glass coating	26401270	Radio broadcast receivers for motor vehicles with sound recording or reproducing apparatus	0,006%	27%
Glass coating	26401290	Radio broadcast receivers for motor vehicles, n.e.c.	0,006%	27%
Glass coating	26301300	Television cameras (including closed circuit TV cameras) (excluding camcorders)	0,006%	27%
Glass coating	26403300	Video camera recorders	0,006%	27%
Glass coating	29102100	Vehicles with spark-ignition engine of a cylinder capacity <= 1 500 cm^3, new	0,000009%	78%
Glass coating	29102230	Motor vehicles with a petrol engine > 1500 cm^3 (including motor caravans of a capacity > 3000 cm^3) (excluding vehicles for transporting >= 10 persons, snowmobiles, golf cars and similar vehicles)	0,000009%	78%
Glass coating	29102250	Motor caravans with a spark-ignition internal combustion reciprocating piston engine of a cylinder capacity > 1500 cm^3 but <= 3000 cm^3	0,000009%	78%
Glass coating	29102310	Motor vehicles with a diesel or semi-diesel engine <= 1500 cm^3 (excluding vehicles for transporting >= 10 persons, snowmobiles, golf cars and similar vehicles)	0,000009%	78%
Glass coating	29102330	Motor vehicles with a diesel or semi-diesel engine > 1500 cm^3 but <= 2500 cm^3 (excluding vehicles for transporting >= 10 persons, motor caravans, snowmobiles, golf cars and similar vehicles)	0,000009%	78%

End-use market	Rev.2 Code	Description	Average In content (% w/w)	RSD
Glass coating	29102340	Motor vehicles with a diesel or semi-diesel engine > 2500 cm³ (excluding vehicles for transporting >= 10 persons, motor caravans, snowmobiles, golf cars and similar vehicles)	0,000009%	78%
Glass coating	29102350	Motor caravans with a compression-ignition internal combustion piston engine (diesel or semi-diesel) of a cylinder capacity > 1500 cm³ but <= 2500 cm³	0,000009%	78%
Glass coating	29102400	Other motor vehicles for the transport of persons (excluding vehicles for transporting >= 10 persons, snowmobiles, golf cars and similar vehicles)	0,000009%	78%
Metallurgy	24422650	Aluminium alloy tubes and pipes (excluding hollow profiles, tubes or pipe fittings, flexible tubing, tubes and pipes prepared for use in structures, machinery or vehicle parts, or the like)	0,001%	26%
Metallurgy	24431350	Unwrought tin alloys (excluding tin powders and flakes)	0,004%	27%
Metallurgy	24431190	Unwrought lead (excluding lead powders or flakes, unwrought lead containing antimony, refined)	0,000004%	27%
Metallurgy	24431250	Unwrought zinc alloys (excluding zinc dust, powders and flakes)	0,000004%	27%
Metallurgy	25931550	Coated rods and cored wire, of base metal, for soldering, brazing or welding by flame (excl. wire and rods cored with solder which, excl. the flux material, contains >= 2% by weight of precious metal)	0.001%	32%
Metallurgy	32505010	Dental cements and other dental fillings; bone reconstruction cements	0.0002%	27%
Metallurgy	25931510	Base metal coated electrodes for electric arc-welding	0.001%	32%
Metallurgy	25931530	Base metal cored wire for electric arc-welding (excluding wire and rods of cored solder, the solder consisting of an alloy containing 2 % or more by weight, of any one precious metal)	0.001%	32%
Electrical and semiconductors	26112220	Semiconductor light emitting diodes (LEDs)	4.4%	25%
Electrical and semiconductors	26112240	Photosensitive semiconductor devices; solar cells, photo-diodes, photo-transistors, etc	0,00002%	22%
Electrical and semiconductors	27201100	Primary cells and primary batteries - Manganese dioxide*	0.0005%	33%
Research and other uses	23192330	Laboratory, hygienic or pharmaceutical glassware whether or not graduated	0.004%	27%
Research and other uses	20595210	Composite diagnostic or laboratory reagents, including paper impregnated or coated with diagnostic or laboratory reagents	0.000004%	17%

*NACE Rev.1.1 records for codes 31401111, 31401112, and 31401113 have been also included in the analysis.

Table S8. Lifetime statistics by end-use application of indium (Harper et al. 2015).

End-use	Average lifetime	Shape parameter	Distribution type
Glass coating	6.5	2.8	Weibull
Metallurgy	13.4	2.2	Weibull
Electrical and semiconductors	13.4	2.2	Weibull
Research and other uses	5	0.5	Normal

Table S9. Life cycle inventory of indium recovery from end-of-life liquid crystal displays (LCD). Material and energy inputs refer to the processing of 100 kg LCD waste. Modified from (Amato et al. 2017).

Input flow	Unit	Value	Main step
Electricity	kWh	1.6	Shredding; washing and water treatment; leaching; cementation
Water	kg	36.6	Washing and water treatment; leaching
Ferrous sulfate	kg	12.2	Washing and water treatment
Hydrogen peroxide	kg	8.2	Washing and water treatment
Sulfuric acid	kg	2.6	Leaching
Sodium hydroxide	kg	1.4	Cementation
Zinc	kg	0.04	Cementation

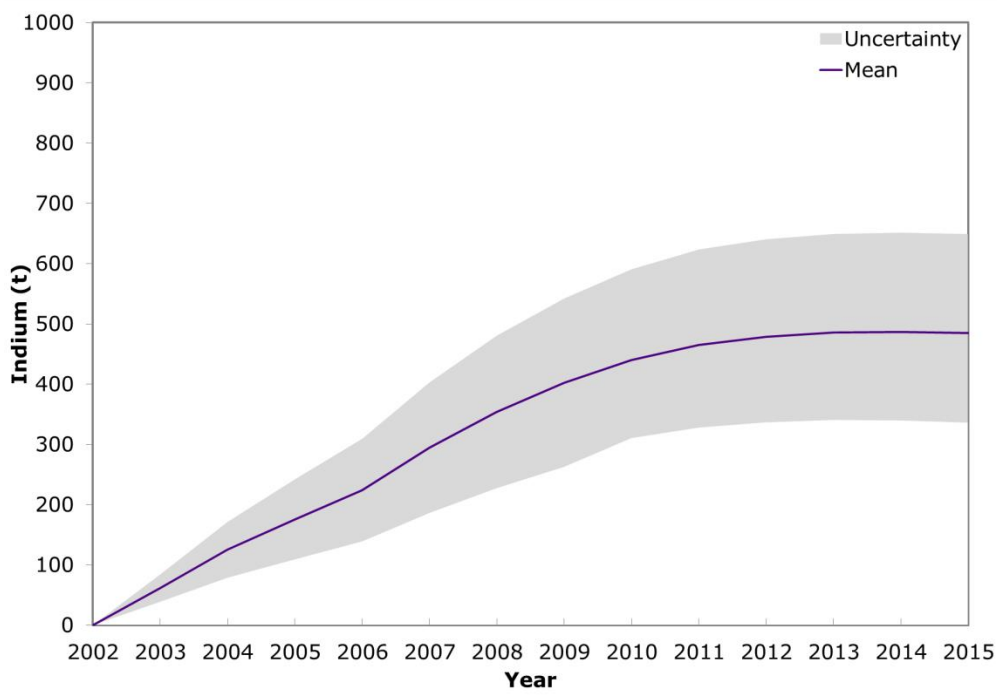

Figure S1. Uncertainty analysis results. The grey area was estimated using lower and upper bound data computed from table S7. Values are in tonnes of indium.

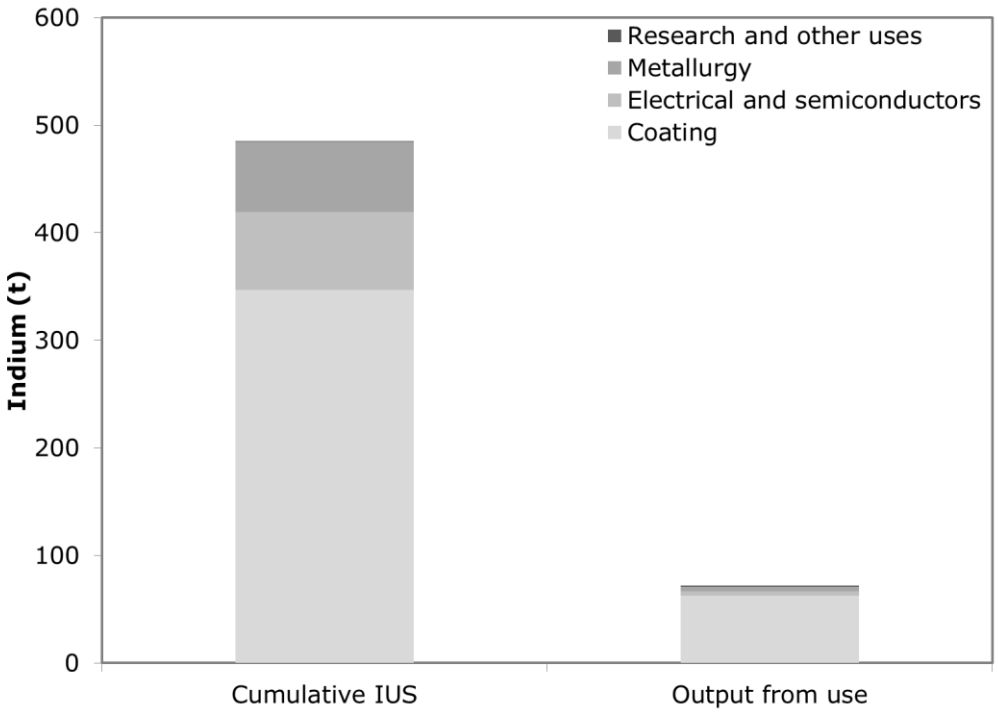

Figure S2. Comparison between the indium cumulative in-use stock (IUS) and the output from use estimated by major application segment of indium. Values are in tonnes of indium.

References

Amato, A., L. Rocchetti, and F. Beolchini. 2017. Environmental impact assessment of different end-of-life LCD management strategies. *Waste Management* 59: 432-441.

Andersson, B. A. 2000. Materials availability for large-scale thin-film photovoltaics. *Progress in Photovoltaics: Research and Applications* 8(1): 61-76.

Baldè, C. P., F. Wang, and R. Kuehr. 2016. Transboundary movements of used and waste electronic and electrical equipment: United Nations University, Vice Rectorate in Europe – Sustainable Cycles Programme (SCYCLE), Bonn, Germany.

Brown, T. J., S. F. Hobbs, N. E. Idoine, A. J. Mills, C. E. Wirighton, and E. R. Raycraft. 2016. European Mineral Statistics 2010-14: A product of the World Mineral Statistics database. British Geological Survey, Keyworth, Nottingham.

Buchert, M., A. Manhart, D. Bleher, and D. Pingel. 2012. Recycling critical raw materials from waste electronic equipment: Commissioned by the North Rhine-Westphalia State Agency for Nature, Environment and Consumer Protection. Oeko-Institut e.V., Darmstadt.

Chancerel, P., V. S. Rotter, M. Ueberschaar, M. Marwede, N. F. Nissen, and K.-D. Lang. 2013. Data availability and the need for research to localize, quantify and recycle critical metals in information technology, telecommunication and consumer equipment. *Waste Management & Research* 31(10_suppl): 3-16.

Chang, T.-C., F.-C. Yen, and W.-H. Xu. 2015. Substance Flow Analysis of Indium in Taiwan. *Materials transactions* 56(9): 1573-1578.

Cucchiella, F., I. D'Adamo, S. C. Lenny Koh, and P. Rosa. 2015. Recycling of WEEEs: An economic assessment of present and future e-waste streams. *Renewable and Sustainable Energy Reviews* 51: 263-272.

Cullbrand, K. and O. Magnusson. 2011. The use of potentially critical materials in passenger cars: Chalmers University of Technology, Gothenburg, Sweden.

Eurostat. 2017. Easy Comext. Accessed on June 2017.

Harper, E. M., G. Kavlak, L. Burmeister, M. J. Eckelman, S. Erbis, V. Sebastian Espinoza, P. Nuss, and T. E. Graedel. 2015. Criticality of the Geological Zinc, Tin, and Lead Family. *Journal of Industrial Ecology* 19(4): 628-644.

Mikolajczak, C. 2017. Indium Corporation. Personal communication.

Nakajima, K., K. Yokoyama, K. Nakano, and T. Nagasaka. 2008. Substance Flow Analysis of Indium for Flat Panel Displays in Japan. *Journal of the Japan Institute of Metals and Materials* 72(2): 99-104.

Rocchetti, L., A. Amato, and F. Beolchini. 2016. Recovery of indium from liquid crystal displays. *Journal of Cleaner Production* 116: 299-305.

Solar Frontier K. K. 2016. Product Brochure. Solar Frontier K. K., p.12.

Survey, U. S. G. 2017. Indium. In Mineral Commodities Summary; U.S. Geological Survey.

Takahashi, K., A. Sasaki, G. Dodbiba, J. Sadaki, N. Sato, and T. Fujita. 2009. Recovering Indium from the Liquid Crystal Display of Discarded Cellular Phones by Means of Chloride-Induced Vaporization at Relatively Low Temperature. *Metallurgical and Materials Transactions A* 40(4): 891-900.

Werner, T. T., L. Ciacci, G. M. Mudd, B. K. Reck, and S. A. Northey. 2018. Looking Down Under for a circular economy of indium. Environmental Science &Technology, DOI: 10.1021/acs.est.7b05022.

Widmer, R., X. Du, O. Haag, E. Restrepo, and P. A. Wäger. 2015. Scarce Metals in Conventional Passenger Vehicles and End-of-Life Vehicle Shredder Output. *Environmental science & technology* 49(7): 4591-4599.