The sustainability metrics

Sustainable development progress metrics

Recommended for use in the process industries

IChemE

Institution of Chemical Engineers

Foreword

I am pleased that IChemE's Sustainability Metrics are now ready for issue. The document is the result of three years work and debate by a number of individuals drawn from industry, academia and consultancy. The people on the attached list deserve all our thanks for their contributions and particularly their perseverance.

The emphasis in our work has been to produce a practical tool for practicing engineers using as far as possible information already available. Our aim has also been to develop a wider understanding of sustainability within the process industry sector.

I very much hope that you will find the metrics useful in measuring your company's progress towards a more sustainable operation and that you will share your experience via IChemE so that we can all learn to improve.

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Summary

The Institution of Chemical Engineers sees sustainable development as the most significant issue facing society today. Engineering for sustainable development means providing for human needs without compromising the ability of future generations to meet their needs. The impact of industry on sustainability can be summarised in the "triple bottom line", covering the three components - environmental responsibility, economic return (wealth creation), and social development. For industry to guide its activities towards greater sustainability, more engineers need to have the tools to assess the operations with which they are concerned. This publication therefore introduces a set of indicators that can be used to measure the sustainability performance of an operating unit. These metrics will help engineers address the issue of sustainable development. They will also enable companies to set targets and develop standards for internal benchmarking, and to monitor progress year-on-year.

The Sustainability Metrics has been produced by the Sustainable Development Working Group of The Institution of Chemical Engineers.

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1 Introduction

The Institution of Chemical Engineers (IChemE), represents 33,000 chemical engineers worldwide and sees sustainable development as the most significant issue facing society today. IChemE's approach to sustainable development is encapsulated in the London Communiqué of 1997 (a statement signed by the leaders of 18 chemical engineering societies throughout the world): "We will work to make the world a better place for future generations" and to "provide the processes and products which will give the people of the world shelter, clothing, food and drink, and which keep them in good health". IChemE has thus been working, with other bodies, to encourage progress to a more sustainable world through the activities of its members and the organizations for which they work.

The laws of conservation of mass and energy are basic principles utilised by engineers. However the results of manipulating the resources of the planet through these principles have consequences for the global eco-system. Engineering for sustainable development means providing for human needs without compromising the ability of future generations to meet their needs. It is clear that we have to be less profligate in our use of non-renewable resources if the planet is to be fit for future generations to live on. We must also be more aware of the consequences of our activities for society at large.

The process industries have made significant progress over the last decade, particularly in improving their efficiency of production and their environmental performance, and IChemE has lent support to this improvement. However, moving towards the goal of sustainability requires us also to examine and improve other aspects that have not traditionally been given much attention, at least by practicing engineers.

Broadly, the impact of industry can be summarised in the "triple bottom line", covering the three components of sustainable development which are environmental responsibility, economic return (wealth creation), and social development.

Many companies now recognize and monitor these three parallel strands, using their assessment to guide their product, process and personnel development and to secure their position in the rapidly changing climate of environmental legislation and stakeholder concerns. IChemE would like to encourage more companies to follow this lead, which requires more engineers to have the tools to assess the sustainability of operations with which they are concerned.

This publication therefore introduces a set of indicators that can be used to measure sustainability performance of an operating unit. If comparable statistics are gathered from a number of operations, they can be aggregated to present a view of a larger operation, on a company, industry or regional basis for example. The operating unit envisaged is a process plant, a group of plants, part of a supply chain, a whole supply chain, a utility or other process system.

We believe that these metrics will help engineers address the issue of sustainable development, and learn about the broader impact of company operations. They will also enable companies to set targets and develop standards for internal benchmarking, and to monitor progress year-on-year.

IChemE would welcome your comments on these metrics, which we hope to develop in the light of experience with their use.

2 Reporting format

Companies in the processing sector are encouraged to report their performance according to the standards recommended by the Global Reporting Initiative (Sustainability Reporting Guidelines, www.globalreporting.org). The format recommended here is in the spirit of the GRI. Naturally the contents of the report will depend on the scope of the operations under consideration, but it is important that even for small operating units the wider implications and impacts are considered.

The report should include the following.

1 Profile

Definition of reporting unit, its boundaries and activities. Any significant changes over reporting period.

2 Summary

Key indicators - environmental, economic and social - which give a balanced overview of the report. Other important comments, conclusions and plans.

3 Vision and strategy

Short-term and long-term actions planned for the unit, to move to greater sustainability. Explanation of how these harmonise with company policy. Identification of specific targets.

4 Policy and organization

Description of policies and organisation, management structure, stakeholder interactions – how these impact on unit performance. Statement on compliance with ISO 14001, EMAS, Responsible Care, etc. Procedures for monitoring sustainability performance of suppliers, contractors and outsourced activities in general.

5 Performance

In this section the metrics are reported. It will be helpful also to note historical trends, targets, and factors affecting performance, as an aid to interpretation.

Although designed for internal use, companies are encouraged to publish their progress metrics report, in whole or in part, to demonstrate their commitment to sustainable development. IChemE will be pleased to receive the information collected by each Company, on a confidential basis not for publication. These data will help us to monitor the usefulness of our metrics, and to develop future recommendations for best practice.

Respondents sending data to IChemE are kindly requested to use the Report Form (Appendix C). This can be completed with the aid of the explanatory notes and working tables found in section 3 of this report.

3 The metrics

The metrics are presented in the three groups

- 3.1 Environmental indicators
- 3.2 Economic indicators
- 3.3 Social indicators

which reflect the three components of sustainable development.

Not all the metrics we suggest will be applicable to every operating unit. For some units other metrics will be more relevant and respondents should be prepared to devise and report their own tailored metrics. Choosing relevant metrics is a task for the respondent. Nevertheless, to give a balanced view of sustainability performance, there must be key indicators in each of the three areas (environmental, economic, social).

Most products with which the process industries are concerned will pass through many hands in the chain resource extraction – transport – manufacture – distribution – sale – utilization – disposal – recycling – final disposal. Suppliers, customers and contractors all contribute to this chain, so in reporting the metrics it is important that the respondent makes it clear where the boundaries have been drawn.

As with all benchmarking exercises, a company will receive most benefit from these data if they are collected for a number of operating units, over a number of years, on a consistent basis. This will give an indication of trends, and the effect of implementing policies.

A note on ratio indicators

Most of the progress metrics are calculated in the form of appropriate ratios. Ratio indicators can be chosen to provide a measure of impact independent of the scale of operation, or to weigh cost against benefit, and in some cases they can allow comparison between different operations. For example, in the environmental area, the unit of environmental impact per unit of product or service value is a good measure of eco-efficiency. The preferred unit of product or service value is the value added (see section 3.2.1), and this is the scaling factor generally used in this report. However, the value added can sometimes be difficult to estimate accurately, so surrogate measures such as net sales, profit, or even mass of product may be used. Alternatively, a measure of value might be the worth of the service provided, such as the value of personal mobility, the value of improved hygiene, health or comfort. But a well-founded and consistent method of estimating these 'values' must be presented.

3.1 Environmental indicators

These metrics should give a balanced view of the environmental impact of inputs – resource usage, and outputs – emissions, effluents and waste and the products and services produced.

3.1.1 Resource usage

(a) Energy

Imports

	Energy value	Conversion	Primary energy	Quantity used/y	Usage rate
Electricity	kJ	a)	kJ		
Fuel Oil	kJ/kg	1	kJ/kg		
Gas	kJ/kg	1	kJ/kg		
Coal	kJ/kg	1	kJ/kg		
Steam	kJ/kg	a)	kJ/kg		
Other (specify)	kJ/kg	a)	kJ/kg		
Total					

Export

	Energy value	Conversion	Primary energy	Quantity used/y	Usage rate
Electricity	kJ	a)	kJ		
Fuel Oil	kJ/kg	1	kJ/kg		
Gas	kJ/kg	1	kJ/kg		
Coal	kJ/kg	1	kJ/kg		
Steam	kJ/kg	a)	kJ/kg		
Other (specify)	kJ/kg	a)	kJ/kg		
Total					

Note

The Energy Value is multiplied by the Conversion factor to give the Primary Energy Value. It thus corrects for the efficiency of generation and supply of the secondary energy source, to yield comparable figures for the primary energy usage rate. The Conversion factors are available from the suppliers of the energy and will vary from provider to provider.

Total Net Primary Energy Usage rate = Imports – Exports .... GJ/y

Percentage Total Net Primary Energy sourced from renewables .... %

Total Net Primary Energy Usage per kg product .... kJ/kg

Total Net Primary Energy Usage per unit value added .... kJ/£

(b) Material (excluding fuel and water)

Total raw materials used, including packaging	....	te/y
Raw material recycled from other company operations	....	te/y
Raw material recycled from consumer	....	te/y
Raw material used which poses health, safety or environmental hazard (describe hazard)	....	te/y

Total raw materials used per kg product	....	kg/kg
Total raw materials used per unit value added	....	kg/£
Fraction of raw materials recycled within company	....	kg/kg
Fraction of raw materials recycled from consumers	....	kg/kg
Hazardous raw material per kg product	....	kg/kg

(c) Water

Water used in cooling	....	te/y			
Water used in process	....	te/y			
Other water used	....	te/y	Total	....	te/y
Water recycled internally				....	te/y
Net water consumed = Total used – recycled				....	te/y

Net water consumed per unit mass of product	....	kg/kg
Net water consumed per unit value added	....	kg/£

(d) Land

Land occupied by operating unit	....	m^2 (include land needed for ALL activities)
Other land affected by unit's activities	....	m^2 (describe effect)
Total land	....	m^2
Land restored to original condition	....	m^2/y

Total land occupied+affected for value added a)	....	$m^2/(£/y)$
Rate of land restoration (restored per year /total) b)	....	$(m^2/ y)/m^2$

Notes

a) *Land affected might be, eg land used in mining raw material or in dumping waste product.*

b) *The areas of land occupied and affected are those at the start of the reporting period, and the land restored is that area restored during the reporting period.*

3.1.2 Emissions, effluents and waste

The environmental impact categories chosen are a sub-set of those used internationally in environmental management, selected to focus on areas where the process industry's activities are most significant. The environmental burden approach (developed by ICI) is a scientifically sound way to quantify environmental performance. It draws on developments in environmental science to estimate potential environmental impact, rather than merely stating quantities of material discharged.

The environmental impact arising from use of the product must be separately assessed under the appropriate environmental impact headings and reported, see 3.1.3 (a).

Note on the calculation method (for further details see appendices A and B)

The Environmental Burden (EB) caused by the emission of a range of substances, is calculated by adding up the weighted emission of each substance. The weighting factor is known as the "potency factor". Note that because a single substance will contribute differently to different Burdens, each substance will have a number of different potency factors.

$$EB_i = \Sigma W_N \times PF_{i,N}$$

where EB_i = ith environmental burden

W_N = weight of substance N emitted, including accidental and unintentional emissions

$PF_{i,N}$ = potency factor of substance N for ith environmental burden.

The ratio indicator is then found by dividing the Environmental Burden by the value added.

(a) Atmospheric impacts (see appendix A for calculation of environmental burdens)

Atmospheric acidification burden per unit value added [a)]	....	te/£
Global warming burden per unit value added [b)]	....	te/£
Human Health burden per unit value added [c)]	....	te/£
Ozone depletion burden per unit value added [d)]	....	te/£
Photochemical ozone burden per unit value added [e)]	....	te/£

Notes

a) *Atmospheric acidification. EB is te/y sulphur dioxide equivalent.*

b) *Global warming. EB is te/y carbon dioxide equivalent.*

c) *Human health (carcinogenic) effects. EB is te/y benzene equivalent.*

d) *Stratospheric ozone depletion. EB is te/y CFC-11 equivalent.*

e) *Photochemical ozone (smog) formation. EB is te/y ethylene equivalent.*

(b) Aquatic impacts (see appendix B for calculation of environmental burden)

Aquatic acidification per unit value added [a]		....	te/£
Aquatic oxygen demand per unit value added [b]		....	te/£
Ecotoxicity to aquatic life per unit value added [c]	(i) metals	....	te/£
	(ii) other	....	te/£
Eutrophication per unit value added [d]		....	te/£

Notes

a) *Aquatic acidification. EB is te/y of released H+ ions.*

b) *Aquatic oxygen demand. EB is te/y oxygen.*

c) *Ecotoxity to aquatic life. EB is (i) te/y copper equivalent, and (ii) te/y formaldehyde equivalent.*

d) *Eutrophication. EB is te/y phosphate equivalent.*

(c) Impacts to Land

Total Hazardous Solid Waste Disposal	....	te/y (describe hazard)
Total Non-Hazardous Solid Waste Disposal	....	te/y

Hazardous solid waste per unit value added	....	te/£
Non-hazardous solid waste per unit value added	....	te/£

3.1.3 Additional environmental items

Also report where appropriate

a) Duty of care with respect to products and services produced. Environmental impact and mitigating steps taken. This to include issues concerning long-term environmental or health problems arising from process or product, for which the solution is not yet known.

b) Issues concerning environmental impact of plant construction and decommissioning.

c) Compliance. Magnitude and nature of penalties for non-compliance with any local, national or international environmental regulations or agreements.

d) Impacts on protected areas (Sites of Special Scientific Interest, proposed Special Areas of Conservation, National Parks). Impacts on local biodiversity or important habitats.

e) Issues concerning long-term supply of raw materials from non-renewable resources.

f) Other possible relevant metrics.

3.2 Economic indicators

A key element of sustainability is the success of industry in creating wealth. The economic indicators go somewhat further than conventional financial reporting in describing the creation of wealth or value, and in reporting its distribution and reinvestment for future growth. Both human and financial capital are considered. The social consequences of economic activity are explored further in section 3.3.

3.2.1 Profit, value and tax

Sales	....	£/y
Cost of goods, raw materials and services purchased	....	£/y
Value added	....	£/y (see note a)
Gross margin	....	£/y (see note b)
Net income before tax	....	£/y (NIBT)
Taxes (total paid to all taxing authorities)	....	£/y

Value added [a)]	....	£/y
Value added per unit value of sales	....	£/£
Value added per direct employee	....	£/y
Gross margin [b)] per direct employee	....	£/y
Return on average capital employed	....	%/y
Taxes paid, as percent of NIBT	....	%

Notes

a) *Value added by the operation is the value of sales less the cost of goods, raw materials (including energy) and services purchased.*

b) *Gross margin is the value of sales minus all variable costs.*

3.2.2 Investments

(a) Direct

Average capital employed		....	£
(plant, associated infrastructure, stocks, working capital etc.)			
Increase (decrease) in capital employed		....	£/y
Research and Development expenditure		....	£/y
Average number of direct employees (full-time equivalents)			
Number of new employees appointed		....	/y
Number of employees with at least 2 years of post-school education		....	(defined in note a)
Total wages expense		....	£/y
Total benefits expense		....	£/y
Payroll expense = wages + benefits	Total	....	£/y
Total training expense for direct employees		....	£/y

Percentage increase (decrease) in capital employed	....	%/y
R&D expenditure as % sales	....	%
Employees with post-school qualification a)	....	%
New appointments/number of direct employees	....	%/y
Training expense as percentage of payroll expense	....	%

Note

a) Technicians and graduates and others who have had at least two years of education or training after leaving secondary school. They should possess a vocational qualification, degree, or similar.

(b) Indirect

Number of indirect jobs wholly dependent on operating unit	....	
(external, not on company payroll. Full-time equivalents.)		
Investment in education (non-employee) at all levels	....	*£/y*
(schools, colleges, universities and other educational programmes)		
Other philanthropy and charitable gifts and donations	....	*£/y*

Ratio of indirect jobs a)/number of direct employees	....	
Investment in education b)/employee training expense	....	£/£
Charitable gifts as percentage of NIBT c)	....	%

Notes

a) The number of indirect jobs includes contractors with supply or other contract, and also includes workers servicing the operation in any way, or in the local community, whose jobs would disappear or diminish if the operation ceased. This could include teachers, shopkeepers, transport workers, accountants etc. Report full-time equivalents.

b) This item refers to support of educational institutions and programmes not specifically for the benefit of employees. Employee education comes under the heading of training, see above.

c) This metric is a measure of the investment in the community.

3.2.3 Additional economic items

Also report where appropriate

a) Other possible relevant metrics.

3.3 Social indicators

Indicators of social performance reflect the company's attitude to treatment of its own employees, suppliers, contractors and customers, and also its impact on society at large. Good social performance is important in ensuring a company's license to operate over the longer term.

3.3.1 Workplace

(a) Employment situation

Number of employees who have resigned or been made redundant	....	/y
Number of direct employees promoted	....	/y
Working hours lost through absence	....	/y
(all unplanned causes - strikes, sickness, absenteeism etc but not holiday or training)		
Indicative wage and benefit package for highest-paid 10% of employees	....	£/y
Indicative wage and benefit package for lowest-paid 10% of employees	....	£/y

Benefits as percentage of payroll expense	....	%
Employee turnover (resigned+redundant/number employed)	....	%
Promotion rate (number of promotions/number employed)	....	%
Working hours lost as percent of total hours worked	....	%
Income+benefit ratio (top 10%/bottom 10%)	....	

(b) Health and safety at work

Lost time accident frequency (number per million hours worked)	....	
Expenditure on illness and accident prevention/payroll expense	....	£/£

3.3.2 Society

Number of meetings with external stakeholders concerning company operations	....	/y
Indirect benefit to the community resulting from presence of operating unit	....	£/y
Number of complaints registered from members of the public concerning the process or products	....	/y
Number of successful legal actions taken against company or employees for work-related incidents or practices	....	/y

Number of stakeholder a) meetings per unit value added	....	/£
Indirect community benefit b) per unit value added	....	£/£
Number of complaints per unit value added	....	/£
Number of legal actions per unit value added c)	....	/£

Note

a) *External stakeholders include customers, residents and other community groups, local government, non-governmental organizations (NGO's). This metric represents company efforts in communicating with external stakeholders.*

b) *A major social benefit arising from the presence of a successful process industry unit is the dissemination of skills and know-how which are used in the community to create wealth and enhance quality of life. It is difficult to quantify these benefits, but estimates may be made. We suggest to include items such as*

i) *Net value to community of freely published information and know-how*

ii) *Net value to community of training given to contractors and suppliers*

iii) *Net value to community of training given to (ex-)employees.*

These estimates of value should not include direct benefits which have already been included in section 3.2.2. Value may be estimated by considering what it has cost the company to generate the benefit on the one hand, and what society might be willing to pay for it on the other.

c) *This metric is a measure of antisocial behaviour.*

3.3.3 Additional items

Also report where appropriate

a) Issues concerning discrimination, concerning women and minorities or indigenous communities, the number in senior and middle management; programmes to improve employability including focused education or training, and mentoring.

b) Incidents of child labour, forced labour or violation of human rights, on the part of the company, its suppliers or contractors, and public protest concerning such issues. Report positive steps taken in this regard.

c) Performance of suppliers and contractors relative to criteria for their selection. Incidents of non-compliance with sustainability requirements, eg Responsible Purchasing.

d) Other possible relevant metrics.

Appendix A Environmental burdens for emissions to air

Atmospheric acidification

Substance	Potency factor PF	Emissions	
		Tonnes W	EB value = W x PF
SO_2	1		
Ammonia	1.88		
HCl	0.88		
HF	1.6		
NO_2	0.7		
H_2SO_4 mist	0.65		
Total			

The potential of certain released gases to form acid rain and acids to water is the potency factor for atmospheric acidification. The unit of Environmental Burden is te/y sulphur dioxide equivalent.

Substance	Potency factor PF	Emissions	
		Tonnes W	EB value = W x PF
Carbon dioxide	1		
Carbon monoxide	3		
Carbon tetrachloride	1,400		
Chlorodifluoromethane, R22	1,700		
Chloroform	4		
Chloropentafluoroethane, R115	9,300		
Dichlorodifluoromethane, R12	8,500		
Dichlorotetrafluoroethane, R114	9,300		
Difluoroethane	140		
Hexafluoroethane	9,200		
Methane	21		
Methylene chloride	9		
Nitrous Oxide	310		
Nitrogen Oxides (NOx)	40		
Pentafluoroethane, R125	2,800		
Perfluoromethane	6,500		
Tetrafluoroethane	1,300		
Trichloroethane (1,1,1)	110		
Trichlorofluoromethane, R11	4,000		
Trichlorotrifluoroethane, R113	5,000		
Trifluoroethane, R143a	3,800		
Trifluoromethane, R23	11,700		
Volatile Organic Compounds	11		
Total			

Global warming

These potency factors are based on a 100-year integrated time horizon. The unit of Environmental Burden is te/y carbon dioxide equivalent – the global warming potential.

Human health (carcinogenic) effects

Unlike Global Warming, there are no internationally accepted potency factors for Human Health. For this reason, carcinogenic effects are offered as a default set but companies are encouraged to use other sets if they are more appropriate.

The potency factor for this category in the table below has been derived from the reciprocal of the Occupational Exposure Limits (OEL) set by the UK Health and Safety Executive. The OEL for benzene has been chosen as the normalizing factor for this category. For other chemicals take the OEL in mg m-3, calculate the reciprocal and divide it by the reciprocal of the OEL for benzene **(0.0625)** i.e. $PF_{substance} = (OEL_{benzene} / OEL_{substance})$.

Chemicals with an OEL greater than 500 mg m^{-3} will have a minimal impact on the total weighted impact.

The unit of Environmental Burden is te/y benzene equivalent.

Substance	CAS number	Potency factor PF	Emissions	
			Tonnes W	EB value = W x PF
Acrylamide	79-06-1	53.3		
Acrylonitrile	107-13-1	3.6		
Antimony & compounds except stibine, as Sb	7440-36-0	32		
Arsenic & compounds except arsine, as As	7440-38-0	160		
Azodicarbonate	123-77-3	16		
Benzene	71-43-2	1		
Berylium & Compounds		8000		
Bis (chloromethyl) ether	542-88-1	3200		
Buta-1,3-diene	106-99-0	0.73		
Cadmium & Compounds		640		
Cadmium oxide fume	1306-19-0	640		
Carbon disulphide	136-23-6	0.5		
1-Chloro-2,3-epoxypropane	106-89-8	8.4		
Chromium (VI) compounds		320		
Cobalt & Compounds		160		
Cotton dust		6.4		
1,2-dibromoethane	106-93-4	4.1		
1,2-dichloroethane	107-06-2	0.76		
Dichloromethane	75-09-2	0.05		
2-2'-Dichloro-4,4'-methylene dianiline (MbOCA)	101-14-4	3200		
Diethyl sulphate	64-67-5	50		
Dimethyl sulphate	77-78-1	3.8		
2-Ethoxyethanol	110-80-5	0.43		
2-Ethoxyethyl acetate	111-15-9	0.3		
Ethylene oxide	75-21-8	1.7		
Formaldehyde	50-00-0	6.4		
Grain dust		1.6		
Hardwood dust		3.2		
Hydrazine	30-07-2	533.3		
Iodomethane	74-88-4	1.3		
Isocyanates, all		800		
Maleic anhydride	108-31-6	16		
Man-made mineral fibre		3.2		
2-Methoxyethanol	109-86-4	1		
2-Methoxyethyl acetate	110-49-6	0.64		
4-4'-methylenedianiline	101-77-9	200		
Nickel & inorganic compounds		160		

2-Nitropropane	79-46-9	0.8		
Phthalic anhydride	85-44-9	4		
Polychlorinated biphenyls (PCB)	1336-36-3	160		
Propylene oxide	75-56-9	1.33		
Rubber fume		26.7		
Rubber process dust		2.6		
Silica respirable crystalline		53.3		
Softwood dust		3.2		
Styrene	100-42-5	0.04		
o-Toluidine	95-53-4	18		
Triglycidyl isocyanurate (TGIC)	2451-62-9	160		
Trimellite anhydride	552-30-7	400		
Vinylidene chloride	75-35-4	0.4		
Wool process dust		1.6		
Total				

Stratospheric ozone depletion

The potency factor for this category is based on the potential to deplete ozone in the upper atmosphere relative to chlorofluorocarbon – 11 (ODP - the ozone depletion potential). The unit of Environmental Burden is te/y CFC-11 equivalent (CFC-11 is trichlorofluoromethane).

Substance	Potency factor PF	Emissions	
		Tonnes W	EB value = W x PF
CFC - 11	1.0		
CFC - 12	1.0		
CFC - 113	0.8		
CFC - 114	1.0		
CFC - 115	0.6		
CFC - 13	1.0		
CFC - 111	1.0		
CFC - 112	1.0		
CFC - 212	1.0		
CFC - 213	1.0		
CFC - 214	1.0		
CFC - 215	1.0		
CFC - 216	1.0		
CFC - 217	1.0		
halon-1211	3.0		
halon-1301	10.0		
halon-2402	6.0		
Carbon tetrachloride	1.1		
1,1,1-trichloroethane	0.1		
Methyl bromide	0.7		
HCFC-21	0.04		
HCFC-22	0.055		
HCFC-31	0.02		
HCFC-121	0.04		

HCFC-122	0.08		
HCFC-123 (3)	0.02		
HCFC-124 (3)	0.022		
HCFC-131	0.05		
HCFC-132	0.05		
HCFC-133	0.06		
HCFC-141	0.07		
HCFC-141b (3)	0.11		
HCFC-142	0.07		
HCFC-142b (3)	0.065		
HCFC-151	0.005		
HCFC-221	0.07		
HCFC-222	0.09		
HCFC-223	0.08		
HCFC-224	0.09		
HCFC-225	0.07		
HCFC-225ca (3)	0.025		
HCFC-225cb (3)	0.033		
HCFC-226	0.1		
HCFC-231	0.09		
HCFC-232	0.1		
HCFC-233	0.23		
HCFC-234	0.28		
HCFC-235	0.52		
HCFC-241	0.09		
HCFC-242	0.13		
HCFC-243	0.12		
HCFC-244	0.14		
HCFC-251	0.01		
HCFC-252	0.04		
HCFC-253	0.03		
HCFC-261	0.02		
HCFC-262	0.02		
HCFC-271	0.03		
Total			

Photochemical ozone (smog) formation

Potency factors for this category are obtained from the potential of substances to create ozone photochemically. The unit of Environmental Burden is te/y ethylene equivalent.

Substance	Potency factor PF	Emissions	
		Tonnes W	EB value = W x PF
Alkanes			
Methane	0.034		
Ethane	0.14		
Propane	0.411		
n-Butane	0.6		
i-Butane	0.426		

n-Pentane	0.624		
i-Pentane	0.598		
n-Hexane	0.648		
2-Methylpentane	0.778		
3-Methylpentane	0.661		
2,2-Dimethylbutane	0.321		
2,3-Dimethylbutane	0.943		
n-heptane	0.77		
2-Methylhexane	0.719		
3-Methylhexane	0.73		
n-Octane	0.682		
2-Methylheptane	0.694		
n-Nonane	0.693		
2-Methyloctane	0.706		
n-Decane	0.680		
2-Methylnonane	0.657		
n-Undecane	0.616		
n-Dodecane	0.577		
Cyclohexane	0.595		
Methyl cyclohexane	0.732		
Alkenes			
Ethylene	1.0		
Propylene	1.08		
1-Butene	1.13		
2-Butene	0.99		
2-Pentene	0.95		
1-Pentene	1.04		
2-Methylbut-1-ene	0.83		
3-Methylbut-1-ene	1.18		
2-Methylbut-2-ene	0.77		
Butylene	0.703		
Isoprene	1.18		
Styrene	0.077		
Alkynes			
Acetylene	0.28		
Aromatics			
Benzene	0.334		
Toluene	0.771		
o- Xylene	0.831		
m-Xylene	.08		
p- Xylene	0.948		
Ethylbenzene	0.808		
n-Propylbenzene	0.713		
i-Propylbenzene	0.744		
1,2,3-Trimethylbenzene	1.245		
1,2,4- Trimethylbenzene	1.324		
1,3,5- Trimethylbenzene	1.299		
o-Ethyltoluene	0.846		
m-Ethyltoluene	0.985		
p-Ethyltoluene	0.935		

3,5-Dimethylethylbenzene	1.242		
3,5-Diethyltoluene	1.195		
Aldehydes			
Formalhyde	0.554		
Acetaldehyde	0.65		
Propionaldehyde	0.755		
Butyraldehyde	0.77		
i-Butyraldehyde	0.855		
Valeraldehyde	0.887		
Benzaldehyde	-0.056*		
Ketones			
Acetone	0.182		
Methylethylketone	0.511		
Methyl- i -butylketone	0.843		
Cyclohexanone	0.529		
Alcohols			
Methyl alcohol	0.205		
Ethyl alcohol	0.446		
i-Propanol	0.216		
n-Butanol	0.628		
i-Butanol	0.591		
s-Butanol	0.468		
t-Butanol	0.191		
Diacetone alcohol	0.617		
Cyclohexanol	0.622		
Esters			
Methyl acetate	0.046		
Ethyl acetate	0.328		
n-Propyl acetate	0.481		
i-Propyl acetate	0.291		
n-Butyl acetate	0.511		
s-Butyl acetate	0.452		
Organic Acids			
Formic acid	0.003		
Acetic acid	0.156		
Propionic acid	0.035		
Ethers			
Butyl glycol	0.629		
Propylene glycol methyl ether	0.518		
Dimethyl ether	0.263		
Methyl- t -butyl ether	0.268		
Halocarbons			
Methyl chloride	0.035		
Methylene chloride	0.031		
Methylchloroform	0.002		
Tetrachloroethylene	0.035		
Trichloroethylene	0.075		
Vinyl chloride	0.272		
1,1-Dichloroethylene	0.232		
cis 1,2- Dichloroethylene	0.172		

trans 1,2- Dichloroethylene	0.101		
Other Pollutants			
Nitric oxide	-0.427*		
Nitrogen dioxide	0.028		
Sulphur dioxide	0.048		
Carbon monoxide	0.027		
Total			

* The negative values imply the ability to reduce photochemical ozone production.

Appendix B Environmental burdens for emissions to water

Substance	Potency factor PF	Emissions	
		Tonnes W	EB value = W x PF
Sulphuric acid	0.02		
Hydrochloric acid	0.027		
Hydrogen fluoride	0.05		
Acetic acid	0.02		
Total			

Aquatic acidification

The potency factor is the mass of hydrogen ion released by unit mass of acid i.e. the number of hydrogen ions released divided by the molecular weight. The unit of Environmental Burden is te/y of H+ ions released.

The calculation of the H+ ion is the preferred method of deriving the potency factor in this category, however measured pH values may also be used.

Substance	Potency factor PF	Emissions	
		Tonnes W	EB value = W x PF
Acetic acid	1.07		
Acetone	2.09		
Ammonium nitrate in solution	0.8		
Ammonium sulphate in solution	1		
Chlorotrifluoroethane	0.54		
1,2 – Dichloroethane (EDC)	0.81		
Ethylene	1		
Ethylene glycol	1.29		
Ferrous ion	0.14		
Methanol	1.5		
Methyl methacrylate	1.5		
Methylene Chloride	0.47		
Phenol	2.38		
Vinyl chloride	1.28		
Total			

Aquatic oxygen demand

The Stoichiometric Oxygen Demand (StOD) has been chosen as the potency factor. It represents the maximum potential of emissions to water to remove dissolved oxygen that would otherwise support fish and other aquatic life. StOD is expressed as tonnes of oxygen required per tonne of substance. The unit of Environmental Burden is te/y oxygen.

An alternative potency factor is Chemical Oxygen Demand (COD).

Calculation of the Stoichiometric Oxygen Demand (StOD)

From knowledge of the chemical structure, calculate the empirical formula as follows:

$C_cH_hN_nCl_{Cl}Na_{Na}O_oP_pS_s$

Then calculate the StOD in te O_2 per te of substance from the equation:

StOD = 16(2c+0.5(h-Cl)+2.5n+3s+2.5p+0.5Na - o)/Molecular Weight

This equation assumes that nitrogen is oxidized and eventually released as the nitrate ion (NO_3-). It is assumed that carbon is mineralized to CO_2, hydrogen (H) to H_2O, phosphorus (P) to P_2O, sodium (Na) to Na_2O, sulphur (S) to SO_2 and halides (represented by Cl) to their respective acids. The compounds described after oxidation are those specified by international convention for calculating oxygen demand.

For example, Acetic acid CH3COOH with a molecular weight of 60

StOD = 16(2´2 + 0.5´4 - 2)/60 = 1.07 te O_2 per te acetic acid

Another example, Phenol C6H5OH with a molecular weight of 94

StOD = 16(2´6 + 0.5´6 - 1)/94 = 2.38 te O_2 per te of phenol

For ionic species the calculation must take into account the charge of the ionic unit. For the ammonium ion (NH4+), for example, we remove an H+ ion and calculate on the NH3, so that the ionic balance is not disturbed.

StOD = 16(0.5x3 + 2.5x1)/17 = 3.76 te O_2 per te of ammonia

= 3.56 te O_2 per te of ammonium ion

Ecotoxicity to aquatic life (values for sea water conditions)

(i) Metals

Substance	Potency factor PF	Emissions	
		Tonnes W	EB value = W x PF
Arsenic	0.2		
Cadmium	2.0		
Chromium	0.33		
Copper	1		
Iron	0.005		
Lead	0.2		
Manganese	0.1		
Mercury	16.67		
Nickel	0.17		
Vanadium	0.05		
Zinc	0.125		
Total			

The potency factor is equal to the reciprocal of the Environmental Quality Standard (EQS) divided by the reciprocal of the EQS of copper. The unit of Environmental Burden is te/y copper equivalent.

(ii) Other substances

Substance	Potency factor PF	Emissions	
		Tonnes W	EB value = W x PF
Ammonia	0.24		
Benzene	0.17		
Carbon tetrachloride	0.42		
Chloride	0.5		
Chlorobenzene	1.0		
Chloroform	0.42		
Cyanide	1.0		
1,2-Dichloroethane (EDC)	0.5		
Formaldehyde	1.0		
Hexachlorobenzene	166.67		
Hexachlorobutadiene	50		
Methylene chloride	0.5		
Nitrobenzene	0.25		
Nitrophenol	0.5		
Toluene	0.125		
Tetrachloroethylene (PER)	0.5		
Trichloroethylene (TRI)	0.5		
Xylenes	0.17		
Total			

The above potency factors are equal to the reciprocal of the Environment Quality Standard (EQS) divided by the reciprocal of the EQS of formaldehyde. The unit of Environmental Burden is te/y formaldehyde equivalent.

Eutrophication

Substance	Potency factor PF	Emissions	
		Tonnes W	EB value = W x PF
NO_2	0.2		
NO	0.13		
NO_x	0.13		
Ammonia	0.33		
Nitrogen	0.42		
PO_4 (III-)	1		
Phosphorus	3.06		
COD	0.022		
Total			

Eutrophication is defined as the potential for over-fertilisation of water and soil, which can result in increased growth of biomass. The species above are those considered to be responsible for eutrophication. The unit of Environmental Burden is te/y phosphate equivalent.

Appendix C Report form

Name of company and unit:	
Contact person:	Job title:
Address:	
Phone and fax numbers:	Email address:

Period covered by the report:

Signed:
Place:
Date:

This page containing company information will be kept by IChemE separately from the following report. The reported data and metrics will thus be anonymous, providing respondents themselves do not reveal their identity in the report.

Report

1	Profile: statement attached	Yes ❑ No ❑
2	Summary: statement attached	Yes ❑ No ❑
3	Vision and strategy: statement attached	Yes ❑ No ❑
4	Policy and organisation: statement attached	Yes ❑ No ❑
5	Performance: statement attached	Yes ❑ No ❑

Metrics should be reported below.

Resource usage

Total Net Primary Energy Usage rate = Imports – Exports	....	GJ/y
Percentage Total Net Primary Energy sourced from renewables	....	%
Total Net Primary Energy Usage per kg product	....	kJ/kg
Total Net Primary Energy Usage per unit value added	....	kJ/£
Total raw materials used per kg product	....	kg/kg
Total raw materials used per unit value added	....	kg/£
Fraction of raw materials recycled within company	....	kg/kg
Fraction of raw materials recycled from consumers	....	kg/kg
Hazardous raw material per kg product	....	kg/kg

Describe hazard

Net water consumed per unit mass of product	....	kg/kg
Net water consumed per unit value added	....	kg/£
Total land occupied+affected for value added	....	$m^2/(£/y)$

Describe effect

Rate of land restoration (restored per year /total)	....	$(m^2/y)/m^2$
Emissions, effluents and waste Atmospheric acidification burden per unit value added	....	te/£
Global warming burden per unit value added	....	te/£
Human Health burden per unit value added	....	te/£
Ozone depletion burden per unit value added	....	te/£

Photochemical ozone burden per unit value added		....	te/£
Aquatic acidification per unit value added		....	te/£
Aquatic oxygen demand per unit value added		....	te/£
Ecotoxicity to aquatic life per unit value added	(i) metals	....	te/£
	(ii) other	....	te/£
Eutrophication per unit value added		....	te/£
Hazardous solid waste per unit value added		....	te/£

Describe hazard

Non-hazardous solid waste per unit value added	....	te/£

Additional environmental items

Statement attached Yes ❑ No ❑

Profit, value and tax

Value added	....	£/y
Value added per unit value of sales	....	£/£
Value added per direct employee	....	£/y
Gross margin per direct employee	....	£/y
Return on average capital employed	....	%/y
Taxes paid, as percent of NIBT	....	%

Investments

Percentage increase (decrease) in capital employed	....	%
R&D expenditure as % sales	....	%
Employees with post-school qualification	....	%
New appointments/number of direct employees	....	%
Training expense as percentage of payroll expense	....	%
Ratio of indirect jobs/number of direct employees	....	
Investment in education/employee training expense	....	£/£
Charitable giving as percentage of NIBT	....	%

Additional economic items

Statement attached Yes ❑ No ❑

Workplace

Benefits as percentage of payroll expense	....	%
Employee turnover (resigned+redundant/number employed)	....	%
Promotion rate (number of promotions/number employed)	....	%
Working hours lost as percent of total hours worked	....	%
Income+benefit ratio (top 10%/bottom 10%)	....	
Lost time accident frequency (number per million hours worked)		
Expenditure on illness and accident prevention/payroll expense	....	£/£

Society

Number of stakeholder meetings per unit value added	....	/£
Indirect community benefit per unit value added	....	£/£
Number of complaints per unit value added	....	/£
Number of legal actions per unit value added	....	/£

Additional social items

Statement attached Yes ❑ No ❑

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