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Proposal for Energy and CO_2 Emission Indicators in the Petrochemical Sector

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Introduction

The chemical and petrochemical industry is the largest industrial consumer of energy, accounting for 31.6 EJ or 30% of industrial energy use. More than half (16 EJ/yr) of the total energy used is accounted for by feedstocks (also called non-energy use). Most of the carbon from oil and natural gas feedstock is “locked” into final products such as plastics, solvents, ammonia and methanol.

Three-quarters of all feedstock is oil and is used for the production of intermediate chemical products like olefins (ethylene and propylene) and aromatics (benzene, toluene and xylenes). These chemicals are further processed into a wide range of plastics, rubbers, resins, solvents and other petrochemical products.

In early 2007 the IEA will publish an in-depth analysis of the energy demand, CO_2 emissions and CO_2 emission reduction opportunities in industry. For each industrial sub-sector the goal is to conduct an in-depth analysis of individual countries that account for at least 80% of total production in that sub-sector. This study sets out the production data requirements and aims to outline the methodology for developing the appropriate indicators to allow for an analysis of the main trends on a country level and to allow for a proper comparison of country level efficiency data. Next steps are to discuss this data and potential analysis with stakeholders to further refine the data and fill in missing information.

Energy indicators

Indicators for petrochemicals are different than for other sectors because most carbon and a large share of the feedstock energy content are stored in the products. As most of the carbon is stored in products, three areas are of similar importance in the long term: energy efficiency in production processes, biomass feedstock and recovery of waste materials.

We propose four indicators: 1) an energy efficiency index based on final energy use which looks at efficiency in the production process; 2) a primary energy equivalent index based on the first indicator; 3) a full life cycle index which credits the use of renewable feedstock and recycling / energy recovery; and 4) a CO_2 emissions index. The appropriate CO_2 credit given for energy recovery from synthetic organic waste is debatable.

IEA energy statistics in the chemical sector represent use of fuels for heat-raising and for feedstock use although quantities used for the latter are also shown separately. The chemical sector includes inorganic chemicals, such as ammonia and industrial gases, and organic chemicals, such as petrochemicals and methanol. The petrochemical industry represents, by far, the most important user of fuels for non-energy purposes. It converts fossil fuels (oil, natural gas and coke-oven by products) and biomass carbon to synthetic organic products.

The lack of energy use data on the level of individual products makes individual process indicators infeasible and thus we propose an aggregate product indicator. Much of the energy data necessary to perform a more detailed analysis is not available due to anti-trust issues, limitations on statistical data and site energy integration. Ideally this indicator would only cover petrochemical products, but as IEA energy statistics also include inorganic chemicals our analysis includes all products in the chemical and petrochemical sector. We have identified 57 products to be included in this aggregate indicator. These products represent more than 95% of all energy used in the Chemical and Petrochemicals sector.

Energy efficiency index methodology

Our proposed methodology for calculating an energy efficiency index is as follows:

1) Use IEA energy statistics for final energy use in Chemical and Petrochemical sector.
2) Define a Best Available Technology (BAT) value for each of the 57 products to be included.
3) Multiply production volumes and BAT to calculate practical minimum energy use.
4) Divide practical minimum energy use and actual energy use (final energy). This is the energy efficiency index.
5) 1 – Energy efficiency index = improvement potential.

Feedstock energy use is included. Production volumes for Benzene, Toulene and Xylene have been split between production from steam cracking and naphtha extraction. This split has been calculated based on the production volume of ethylene and is necessary due to the more energy intensive nature of production from steam cracking versus naphtha extraction. In addition BTX produced from naphtha extraction will generally be produced at the refinery which may lead to some accounting inaccuracies in IEA energy statistics as energy use for petrochemicals produced at the refinery will most likely be accounted for under the refinery sector and not the Chemical and Petrochemical sector. The same split and potential accounting inaccuracies also apply for Propylene from steam cracking and FCC. Energy use for Paraffin, which is produced at the refinery, may also lead to accounting inaccuracies.

Table 1 below lists the 57 most energy intensive products in the Chemical and Petrochemical sector used to calculate our energy efficiency index. BAT values have been broken down into electricity, feedstock, heat and steam.

Table 1 – BAT values applied to Chemical and Petrochemical sector, Japan 2003

2003	Production Volume K ton	Electricity GJ/ton	Feedstock GJ/ton	Heat GJ/ton	Steam GJ/ton	Energy Use GJ/ton	Total Energy Use PJ
INORGANIC CHEMICALS							
Ammonia	1,278		21.00	7.00		28.00	35.8
Carbon black	793	1.80	32.80			34.60	27.4
Oxygen	11,247	0.76				0.76	8.5
Sodium hydroxide (& Chlorine)	4,320	9.00		0.60		9.60	41.5
Titanium dioxide	261	7.19		22.00	5.60	34.79	9.1
ORGANIC CHEMICALS							
Acetaldehyde	340	0.29			3.34	3.63	1.2
Acetic acid	576	0.46		30.00	4.48	34.94	20.1
Acetone	464	0.20			9.77	9.97	4.6
Acrylonitrile	777	1.00		-6.00		-5.00	-3.9
Benzene (steam cracking)	1,020	0.92	42.60	20.07	7.01	70.60	72.0
Benzene (naphtha extraction)	3,482		42.60	2.40	5.00	50.00	174.1
Butadiene	1,055	0.54			6.00	6.54	6.9
Butylene	2,975	0.11	47.00	3.00		50.11	149.1
Butanol	503	0.40			3.27	3.67	1.8
Caprolactam	540	1.50				1.50	0.8
Cyclohexane	687	0.10				0.10	0.1
Cumene	1,335	0.00		2.05	-2.80	-0.75	-1.0
Ethylene	7,233	0.20	47.20	12.80		60.20	435.4
Ethylbenzene	3,160	0.07			3.28	3.35	10.6
Ethylene dichloride	3,438	0.23		4.42		4.65	16.0
Ethylene glycol	792	0.26		0.94	4.37	5.57	4.4
Ethylene oxide	907	1.02		3.09		4.11	3.7
Formaldehyde	1,152	0.77	10.00		-4.77	6.00	6.9
Isopropyl alcohol	173	0.09		5.20	5.40	10.69	1.9
Maleic anhydride	109	0.11			2.00	2.11	0.2
Melamine	107	0.11			2.00	2.11	0.2
Metacrylate	455	0.11			2.00	2.11	1.0
Methyl chloride	180	0.11			2.00	2.11	0.4
Methylene chloride	66	0.1			2.0	2.11	0.1
Methyl tert butyl ether	0	0.1			3.9	3.92	0.0
Octanol	297	0.2	40.0			40.18	11.9
Paraffin	176	0.1	45.0		1.0	46.11	8.1
Phenol	871	0.6			9.1	9.75	8.5
Phthalate plasticizers	383	1.3		20.0		21.34	8.2
Phthalic anhydride	265	0.7		20.0		20.70	5.5
Polypropylene glycol	307	3.4		5.3		8.68	2.7
Propylene	3,761	0.2	46.7	13.3		60.22	226.5
Propylene FCC	1,752	0.1	46.7	3.3	1.5	51.61	90.4
Purified terephthalic acid	1,432	0.3			2.6	2.91	4.2
Styrene	3,160				3.6	3.64	11.5
Toluene (steam cracking)	824		43.5	23.5		67.00	55.2
Toluene (naphtha extraction)	754		43.5	6.5	5.0	55.00	41.5
Toluene diisocyanate	211	2.8	24.8		21.7	49.22	10.4
Xylene (steam cracking)	382		41.3	25.7		67.00	25.6
Xylene (naphtha extraction)	4,872		41.3	8.7	5.0	55.00	268.0
p-Xylene	3,143	0.2		6.3	0.8	7.25	22.8
Vinyl chloride monomer	2,891	0.4		2.7		3.08	8.9
PLASTICS							
Phenolic resins	247		20.0		10.0	30.00	7.4
Polycarbonate	396	2.7			12.9	15.52	6.1
Polyethylene, high density	1,126	1.8			1.4	3.20	3.6
Polyethylene, low density	1,797	3.4		0.0		3.37	6.1
Polyethylene terephthalate	1,064	0.7		4.1		4.75	5.1
Polypropylene	2,724	0.4			1.4	1.80	4.9
Polystyrene	1,799	0.4		0.5	0.0	0.91	1.6
Polyvinyl chloride	2,098	0.6			2.2	2.85	6.0
Urea Formaldehyde Resins	113	0.2			2.5	2.69	0.3
Synthetic rubber	1,608	1.0		6.0		7.00	11.3
Practical Minimum Energy Use							**1891**

Source: METI, Neelis et al, IPPC and IEA estimates

Detailed production statistics are not readily available in most countries and as a result we were only able to apply this indicator analysis for Japan. Access to production data on a country level is crucial for this analysis and for most countries this is either publicly unavailable due to anti-trust issues or available only for purchase from intermediates. Although the data maybe difficult or costly to obtain the experience of the NEU CO_2 network indicates that it is possible.[1]

Case study: Japan

Based on the methodology described above we calculated the practical minimum energy use in the Japanese Chemical and Petrochemical sector to be 1891 PJ for 2003. Actual energy use (including feedstock) based on IEA statistics was 2268 PJ. The energy efficiency index for Japan is 0.83, representing a current energy efficiency potential of 17% based on best available technology. The efficiency potential maybe underestimated due to accounting inaccuracies arising from petrochemical products produced at the refinery whose process energy use is accounted under the refining sector in the IEA statistics. This underestimation maybe partially offset as the BAT figures for electricity include only electricity used in the production process and does not include electricity used for heat pumps, motors, lighting and other non process electricity use. Actual energy use in the IEA statistics includes both process and non process electricity use.

Primary energy equivalent index

In addition to the energy efficiency indicator described above we have calculated a primary energy equivalent indicator which also takes into account CHP use in the industry and the country's electricity efficiency ratio. The practical minimum energy use is adjusted for 100% CHP use (based on natural gas) for electricity and assumes a 90% efficiency (electricity and heat). Japan's 2003 primary energy use in the sector was 2632 PJ[2] compared to an adjusted practical minimum energy use of 1926 PJ. This gives a primary energy equivalent index of 0.73 and represents an efficiency potential of 27%.

Life cycle index

A life cycle indicator will be developed to give credit for renewable feedstocks and recovery of waste plastics for use in recycling or energy recovery. We recommend the following methodology for calculating this indicator:

1) Use IEA energy statistics for final energy use in Chemical and Petrochemical sector.
2) Define a BAT value for each of the 57 products to be included.
3) Multiply production volumes and BAT to calculate practical minimum energy use.
4) Add bio-plastics and other synthetic organic materials from natural feedstocks.
5) Add energy use for recycling to actual energy use. Subtract energy recovery (from waste plastics) from actual energy use.
6) Add energy that would have been used in primary olefins and plastics production for the recycled production volume to practical minimum energy use.
7) Divide adjusted practical minimum energy use and adjusted energy use. This is the life cycle index.

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[1] NEU CO_2 is the International Network Non-Energy Use and CO_2 emissions http://www.chem.uu.nl/nws/www/nenergy/

[2] This assumes that a quarter of all electricity required in the Chemical sector in Japan is supplied by CHP plants and the remainder is purchased from the grid. Japan's 2003 average electricity production efficiency was 47%.

Based on the above methodology we have calculated an adjusted energy use of 2259 PJ and an adjusted practical minimum energy use of 2003 PJ, which represents a life cycle index of 0.89 for Japan in 2003. When credit is given for waste plastics recovery we see that the efficiency potential falls from 17% to 11%. Japan's waste plastics recovery represents an efficiency gain of 6%.

CO_2 Emissions Index

The final indicator we propose is a CO_2 emissions index which compares the sector's direct CO_2 emissions with an ideal minimum based on using only natural gas for the BAT based process steam and heat requirements. To make this index comparable across countries we have excluded electricity related emissions from this analysis. Emissions from feedstocks are based on actual feedstock use. In calculating the direct emissions for Japan we have assumed that total carbon storage in plastics is 36.4 Mt of CO_2. Table 2 shows our estimates for carbon storage in plastics for Japan in 2003.

Table2 Carbon storage for plastics in Japan, 2003

	T CO_2 stored / ton product	Mt CO_2 equivalent / year
Polyethylene	3.1	9.2
Polypropylene	3.1	8.6
Polystyrene	3.4	6.0
Polyvinyl chloride	1.4	3.0
Polyethylene terephthalate	3.0	3.2
Polycarbonate	3.0	1.2
Others	2.7	5.3
Total Carbon Storage		**36.4**

Source: METI and IEA estimates

Total direct emissions for the Japanese chemical sector in 2003 were 100 Mt CO_2 compared to an ideal minimum of 84 Mt CO_2. The CO_2 emissions index is 0.84 which represents a 16% potential for CO_2 emissions reduction. This potential reflects not only CO_2 savings from fuel switching, but also reductions related to greater energy efficiency if energy use was based on BAT.

Some of the locked-in energy value can be recovered at a later stage when the product is incinerated, which results in CO_2 emissions at the waste-treatment stage. The appropriate CO_2 credit for energy recovery from plastics waste is unclear and for simplicity sake we have not included energy recovery and plastics recycling in this CO_2 index. We propose to develop a separate life cycle CO_2 index that would include waste-treatment, energy recovery and recycling at a later stage.

Based on our proposed 4 indicators, Japan's energy efficiency and CO_2 emissions reduction potential based on using best available technologies varies from 11% - 27%. Cracker upgrades and increased CHP deployment could provide areas for potential improvement. The installation of a gas turbine in front of all the steam crackers for pre-heating of combustion air is one possible option for efficiency gains.

The advantage of this proposed indicator methodology is that it is feasible based on existing energy data and allows for a country comparison. The disadvantage to this approach is that it is not suited to identify which processes to focus on. The list of products may also be incomplete and accounting issues related to petrochemicals produced at the refinery may underestimate energy efficiency. The practicality of detailed process volume data collection for other countries needs to be investigated further. The quality of IEA energy statistics is not clear, but may be a source of uncertainty.

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