Practice and Technology and Measures For Improving Energy Efficiency in the Chemical and Petrochemical Sector

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1.Theme Description

Energy use grew up from 4.6 Mtoe[1] in 1973 to 13.4 Mtoe in 2012.Total final energy consumption decreased in Europe while it increased in non-OECD countries, reaching a further 1.3% in 2014 (i.e China 3.1% and 4.3% in India).[2],[3]

Figure 1 shows World Energy consumption for OECD and Non-OECD country from 1990 to 2040. As can be seen from 2010 up to 2040, it will grow of 56% from 524 quadrillion of BTU to 820 quadrillion of BTU. The industrial sector will consume more than 50% of the energy in 2040 and this energy will be produced for 80% from fossil fuel.

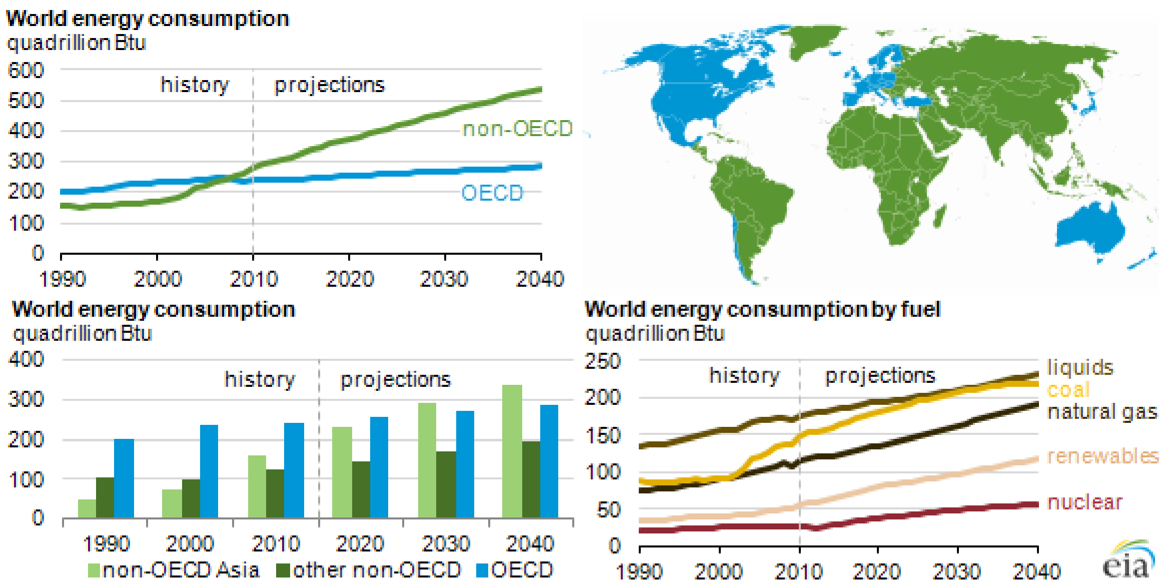

Figure 1 – World Energy Consumption from 1990 up to 2040.[4]

In this scenario Chemical and Petrochemical sectors contribute to a large part of the Industry energy consumption (~ 30% including feedstocks)[5]. Therefore, in the following section, Best Practice Technologies (BPT) that allow to save energy and reduce CO_2 emissions are described.

2.Energy Consumption in Chemical and Petrochemical Sectors

The energy consumption from Industry reached 29% of final energy consumption in 2012 and Chemical and Petrochemical sectors are the largest energy users with 35 EJ[6] (see Figure 2), contributing to about 7% of the global CO_2 emissions.[7]

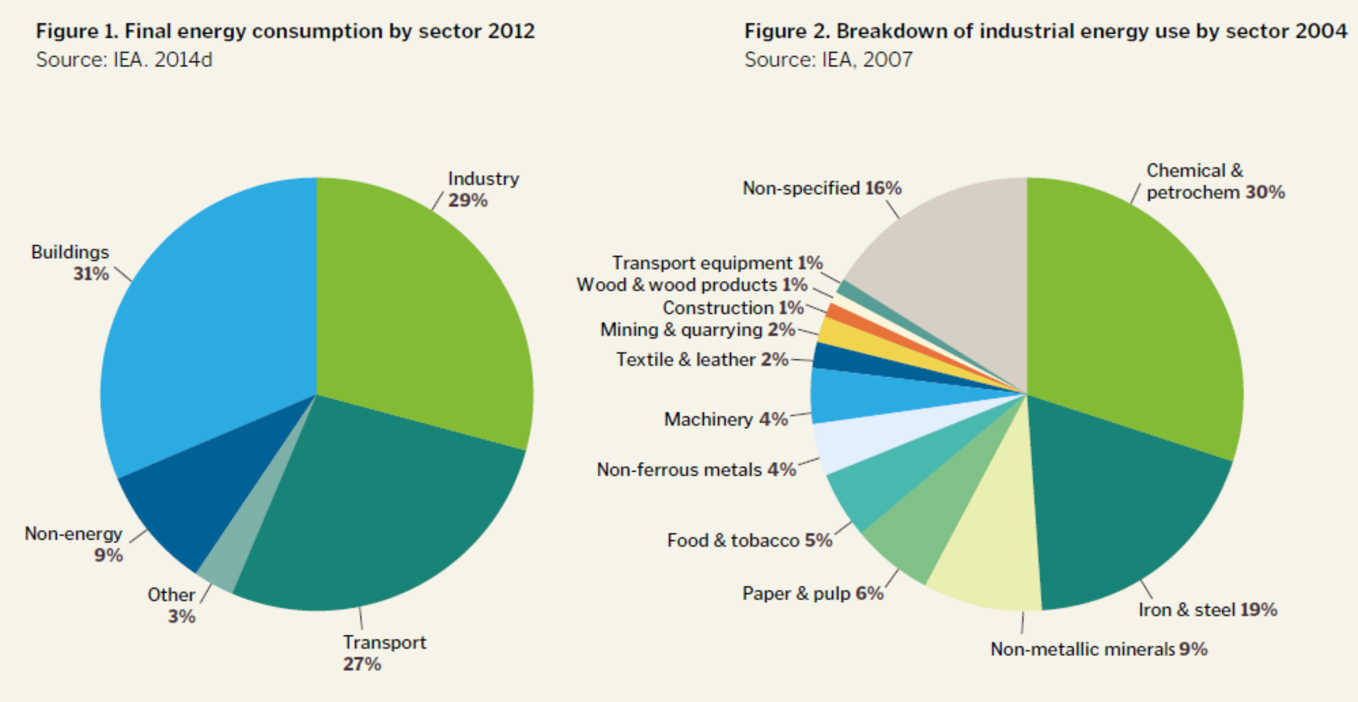

Figure 2 – Energy consumption by sector (figure 1) and Industrial Energy Consumption by sector (figure 2) (2)

The main energy consuming processes are steam cracking, ammonia production from natural gas and coal, extraction of aromatics, methanol and butylene that accounts for about 70% of the consuming.5

The energy efficiency in these sectors has been started since 1970s after oil crisis.

Table 1 and Table 2 show some of the possible measures to increase energy efficiency. In particular, Table 1 refers to the main equipment used in the processes,while Table 2 refers the production of specific chemical compounds.

Equipment, Steam Distribution and Controls	Measures to increase Energy Efficiency

Boiler	• Pretreatment of boiler feed water. • Flue gas analyzer (it improves efficiency and reduce NOx). • Reduce flue gas amount due to leaks in the boiler. • Reduce excess air. • Improve insulation. • Maintenance (i.e. antifouling and antiscaling). • Recover heat (i.e. flue gas and blowdown).
HeatExchanger	• Fouling prevention by means of temperature control, regular maintenance and cleaning, inhibitors and surface coating.
Steam Distribution	• Insulation (low thermal conductivity, resistance to water adsorption, combustion and temperature change). • Steam trap (i.e. maintenance, recovery flash steam). • Recovery of hot condensate.
Electric Motors (pump, compressor and fun)	• Follow standard of NEMA (USA) or IEC (EU). • Use variable speed drivers. • Pump/motor alignment check. • Correct size. • Use multiple pumps. • Replace V-belts with cog belts. • Keep motors and compressor lubricated and cleaning. • Use filter to prevent entry of contaminants.
Distillation	• Optimize the reflux ratio. • Reduce purity when is not necessary in this way the reboiler duty decreases. • Replace trays with new ones. • Replace old column with Divided Wall and Heat Integrated columns.
Control system	• Mathematical (“rule-based”). • Neural Network (“fuzzy-logic”). • Artificial Intelligent.

Table 1 – Methods to Improve Energy Efficiency by referring to specific equipment (for more detail see[8],[9]).

Chemical Compounds Production	Measures to increase Energy Efficiency
Ethylene	• Sulphur-based inhibitor (reduce coke formation in the coil). • Improve furnace coils (i.e. ceramic or ceramic coated). • Integration with a gas turbine. • Use of high-temperature quench oil towers. • Reduce pressure drop in compressor inter-stage.
Aromatics	• Improve energy recovery.
Polymers	• Use power and steam from cogeneration. • Production of low pression steam (i.e. using exothermic heat of the reaction). • Gear pump and/or extruder. • Re-use of solvent, oils and catalysts.
Styrene	• Use of steam condensate instead of low pressure steam.

Table 2 – Methods to Improve Energy Efficiency by referring to specific compounds (for more detail see 8).

2.1 Applications of Emerging Technologies

The main chemical and petrochemical processes (i.e. steam cracking, ammonia production etc.) use catalysts to enhance the velocity of specific reaction increasing the yield. The IEA in collaboration with International Council of Chemical Association (ICCA) and DECHEMA estimated that improvement of catalysts and related processes could reduce energy consumption of 20-40% in 2050.[10]

Recently new processes have been developed to produce these compounds at lower costs:

- **Methanol to Olefin (MTO)**, uses synthetic gas instead of crude oil. UOP and Norsk Hydro (now Ineos) developed a MTO process that allows to increase the yield of ethylene and propylene reducing by-product and catalyst consumption.[11]This process has been tested at semi-commercial scale by Total Petrochemical in Belgium.
- **Hydrogen Peroxide Propylene Oxide (HPPO)**, produces propylene oxide by the reaction of hydrogen peroxide and propylene. The process saves about 10-12% of energy (included hydrogen peroxide production) compared to conventional processes10 avoiding by-products such as propylene dichloride and styrene monomer. One of the biggest commercial plant (300,000 t/year) is in Belgium based on BASF/Dow chemical technologies.[12]
- **Gas to Liquids (GTL)**,where natural gas is converted into liquid fuels such as naphtha, kerosene, diesel etc.[13] Nowadays there are five commercial plants developed by Shell (Malaysia and Qatar), Sasol (South Africa) and joint venture between Sasol and Chevron (Qatar). These plants have a capacity between 2,700 bbl/d up to 140,000 bbl/d and high investment costs[14] (i.e. Shell cancelled a plant in Louisiana due to the jump of the price from 12.5 to over 20 B$[15]). Therefore recently, small GTL plant shave tested. A commercial plant was realized in Brazil by Petrobras and CGTL. It produces 200,000 scf/d and it costed 45US$.[16]

2.2 Indices to evaluate Best Practice

Technologies (BPT)

Nowadays two terms are used to group the most efficient technologies used in the processes:

- **BPT**, means Best Available Technologies and refers to most advanced technologies economically available at industrial scale.
- **BAT**, stands for Best Available Technologies more technologically advanced, but not always economically suitable.

In some cases, the two terms coincide. In the chemical and petrochemical sectors usually refer to BPT.5,[17]

The International Energy Agency (IEA) in the reporton: "*Chemical and Petrochemical: Potential of Best Practice Technology and other measures for improving energy efficiencies*" has defined two different indices for Energy Efficiency and CO_2 savings.

The former is the ratio between the sum of the minimum energy associated to each process and total energy use by chemical and petrochemical processes (Table 3). The last takes into account only direct emissions excluding that related to electricity, use and waste treatments (Table 4).

The value of both indices is function of the approach used. In both **top-down** and **bottom-up** approaches the energy efficiency is the ratio the potential performance of the sector under BTP and the current performance. However, in the top-down approach the BPT values are scaled by a coverage factor set equal to 0.95 for all country. While for bottom-up approach this value is specific for each country. The coverage factor takes into account that not all processes are considered. In the table 3 are shown the results for 57 processes and 66 chemical products. Considering electricity, the improvement potentials reaches 20%.5

Country	TFEU[18] [PJ/y]	$(BPT)_{T-D}$[19] [PJ/y]	$(BPT)_{B-U}$[20] [PJ/y]	$(EEI_j)_{T-D}$[21] [%]	$(EEI_j)_{B-U}$[22] [%]	I_{T-D}[23] [%]	I_{B-U}[24] [%]
USA	6412	4851	5713	75.6	89.1	24.4	10.9
China	4301	4459	3397	103.7	79.0	-3.7	21.0
Germany	1064	1048	931	98.5	87.5	1.5	12.5
India	1096	1113	893	101.5	81.4	-1.5	18.6
France	627	556	563	88.7	89.9	11.3	10.1
Italy	389	348	344	89.5	88.5	10.5	11.5
World	**31,529**	**26,544**	**26,898**	**84.2**	**85.3**	**15.8**	**14.7**

Table 3 – Improvement potentials of main Countries in 2006 (excluding electricity) (6)

The top-down approach underestimates the improving potential for China and India leading to a negative value. While bottom-up approach leads to coverage factor, for some country, more than 100%. Therefore, both methods have critical elements due to overestimation of the process. Indeed, heat cascading and co-generation are neglected.

Country	**Direct CO_2 Emissions [Mt CO_2/y]**	**$(CO_2)_{index-mix}$[25]**		**$(CO_2)_{index-NG}$[26]**	
		T-D [%]	**B-U [%]**	**T-D [%]**	**B-U [%]**
USA	278	0.63	0.81	0.51	0.67
China	148	1.03	0.50	0.47	0.07
Japan	111	0.80	0.87	0.53	0.59
Germany	42	0.95	0.74	0.63	0.46
France	27	0.79	0.80	0.52	0.53
Italy	12	0.73	0.70	0.43	0.40
World	**1,255**	**0.65**	**0.66**	**0.50**	**0.51**

Table 4 – CO_2 savings for main countries in 2006 (5)

The CO_2 savings is equal to:

- 20-37% with the actual fuel mix and 37-57% with natural gas, for a top-down approach;
- 19-50% with actual fuel mix and 33-60% (excluding China) with natural gas for a bottom-up approach.

Finally, in the figure 3 is shown the energy saving potential with BPT and other options such as co-generation, recycling, energy recovery etc.For chemical and petrochemical sectors, the energy saving potential with BPT amount to 120-150 Mtoe/year and 370-470 Mt_{CO2}/year.7

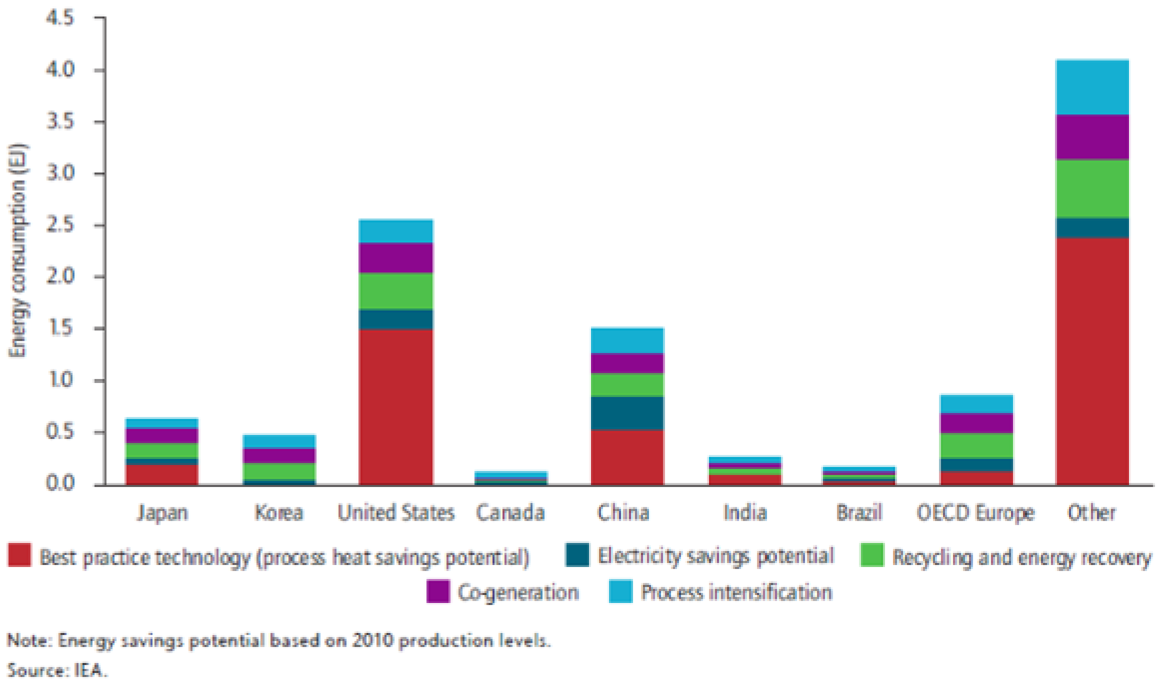

Figure 3 – Comparison between energy saving potential.[27]

3.Conclusions

The Chemical and Petrochemical sectors are the largest energy users within industrial sector and they reached 30% of final consumption in 2012. There are several measures to improve energy efficiencies (Table 1 and Table 2) and some of emerging processes are Methanol to Olefin (MTO), Hydrogen Peroxide Propylene Oxide (HPPO) and Gas to Liquid (GTL). The International Energy Agency (IEA) has defined two indices to evaluate the Energy Efficiencies and CO_2 potential savings by applying Best Practice Technologies (BPT). This term groups the most advanced technologies economically available at industrial scale. The value of these indices depends on the approach used: top-down or bottom-up. The two methods lead to different results but both in some cases overestimate or underestimate the improvement potential. Therefore, it is necessary to consider more data and associate BPT with co-generation, recycling energy and the use of biomass feedstocks. IEA in collaboration with International Council of Chemical Association (ICCA) and DECHEMA, also, define four pathways to be followed in the future: improve feedstock energy (i.e. production of synthetic gas from several raw material), fuel form gas and coal, New routes to polymer (i.e. saccharification of lignocellulose into bioethanol) and hydrogen production (i.e. from biomass, waste material, improve of water electrolysis etc.).[28]

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[1]Mtoe = Million tonnes of equivalent Oil.

[2]S. Fawkes et al., *Best Practice and Case Studies for Industrial Energy Efficiency Improvement, An Introduction for Policy Makers*, Copenhagen Centre of Energy Efficiency, 2016.

[3] https://www.iea.org/etp/tracking2017/industry/

[4] https://www.eia.gov/todayinenergy/detail.php?id=12251

[5]D. Saygin et al.,*Chemical and Petrochemical Sector: Potential of best practice technology and other measures for improving energy efficiency*, OECD/IEA, 2009.

[6]D. Saygin et al., *Potential of best practice technology to improve energy efficiency in the global chemical and petrochemical sector*, Energy 2011, 36, pp 5779-5790.

[7]M. Hagemann et al.,*Development of sectoral indicators for determining potential decarbonization opportunity*, Ecofys and Institute of Energy Economics, Japan 2015.

[8]Maarten Neelis et al., *Energy Efficiency Improvement and Cost Saving Opportunities for the Petrochemical industry, An ENERGY STAR®Guide for Energy and Plant Managers*, Energy Analysis Department Environmental Energy Technologies Division Ernest Orlando Lawrence Berkeley National Laboratory University of California, 2008.

[9]Yeen Chan et al*., Study on Energy Efficiency and Energy Saving Potential in Industry and on Possible Policy Mechanisms*, ICF International, 2015.

[10]http://www.iea.org/publications/freepublications/publication/Chemical_Roadmap_2013_Final_WEB.pdf

[11] https://www.uop.com/processing-solutions/petrochemicals/olefins/#ethylene

[12] http://www.chemicals-technology.com/projects/basf-hppo/

[13] http://petrowiki.org/Gas_to_liquids_(GTL)

[14] https://www.eia.gov/todayinenergy/detail.php?id=15071

[15] https://www.forbes.com/sites/peterdetwiler/2014/03/28/small-gas-to-liquids-plants-get-a-huge-boost/#73330c745419

[16]http://www.compactgtl.com/technology/petrobas/

[17]https://www.iea.org/publications/freepublications/publication/IEA_EnergyEfficiencyIndicators_EssentialsforPolicyMaking.pdf

[18]*TFEU* = actual total final fuel and steam use of a country reported in IEA energy statistics, including feedstocks;

[19]$(BPT)_{T\text{-}D}$= specific final energy consumption under Best Practice Technology for a *Top-Down approach*. This value is scaled according to coverage factor (to take into account that some processes have not been considered)assumed equal to 0.95.

[20]$(BPT)_{B\text{-}U}$= specific final energy consumption under Best Practice Technology for a *Bottom-Upapproach*. This value is scaled according to coverage factor set equal to: 0.82 for the USA, 1.26 for China, 1.20 for India, 1.08 for Germany, 0.95 for France and 0.97 for Italy.

[21]$(EEI)_{T\text{-}D}$ = Energy Efficiencies Indicators for a *Top-Downapproach*.

[22]$(EEI)_{B\text{-}U}$ = Energy Efficiencies Indicators for a *Bottom-Up approach*.

[23]$(I)_{T\text{-}D}$ = Improvement Potential $(1-(EEI)_{T\text{-}D})$ for a *Top-Down approach*.

[24]$(I)_{B\text{-}U}$= Improvement Potential $(1-(EEI)_{B\text{-}U})$ for a *Bottom-Up approach*.

[25] $(CO_2)_{index\text{-}mix}$evaluates the CO2 saving under BPT by means of the same fuel mix in 2006. Referring for example to EU in 2014 fuel mix consist of: Electricity (56%), Gas (32%), Solid Fuel (5%), Total Petroleum Product (4%) and Other (3%). (ref. 9)

[26]$(CO_2)_{NG}$evaluates the CO2 saving under BPT by means of natural gas.

[27] http://www.iea.org/publications/freepublications/publication/technology-roadmap-chemical-industry-via-catalytic-processes.html

[28]

https://www.iea.org/media/freepublications/technologyroadmaps/TechnologyRoadmapCatalyticProcessesAnnexes.pdf