Ethylene

HIGHLIGHTS

Processes and technology status – Ethylene is one of the most important building blocks for production of a wide variety of chemicals such as polyethylene, ethylene oxide, ethylbenzene. Feedstocks for production of Ethylene are hydrocarbons ranging from methane to naphtha. Ethylene can be produced through various routes. The main production route is by steam-cracking of hydrocarbons. The other main routes of ethylene production are methanol-to-olefins (MTO), catalytic dehydration of ethanol, oxidative dehydrogenation of ethane, and, oxidative coupling of methane.

Cost – Average cost of ethylene production from ethylene-propane base steam cracker is 265.49 €$_{2017}$/t$_{Ethylene}$[1] while it is equal to 539.82 €$_{2017}$/t$_{Ethylene}$[2] for the naphtha as feedstock. Since 2008, the availability of low-cost ethane from shale gas has favored the use of pure steam crackers. Manufacturing of ethylene from shale gas results in much lower production costs for ethylene than the conventional naphtha cracking design. However, shale gas routes impose higher costs in terms of life cycle GHG emissions.

Potential and barriers – High emission of carbon dioxide from steam crackers is an essential barrier in front of the main production route of ethylene while, the global demand of ethylene is likely to continue to grow even during the Covid-19 pandemic. In fact, demand for monomers going into polyethylene production is boosted by increased requirements from the packaging sector.

Ethylene – Ethylene is the core chemical product of the petrochemical industry chain. Ethylene and downstream products, such as polyethylene (PE), ethylene glycol and styrene, account for about 75 percent of petrochemical products [1].

Process overview - Ethylene is obtained mainly from cracking of naphtha, gasoil

[1] 1 €$_{2017}$ = 1.13 \$$_{2017}$ [23]
[2] 300 \$$_{2017}$/t$_{Ethylene}$ and 610 \$$_{2017}$/t$_{Ethylene}$ respectively [24]

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and condensates with the coproduction of propylene, C_4 olefins and aromatics (pyrolysis gasoline) [2]. There exist other ethylene productions namely catalytic dehydration of ethanol, oxidative dehydrogenation of ethane (ODH), oxidative coupling of methane and methanol-to-olefins (MTO). Moreover, small quantities of dilute ethylene can be obtained from methanol-to-propylene (MTP) and refinery streams [3]. Details of the steam cracking technology are explained in the previous fact sheet on the Propylene production [4]. For example, the naphtha-based steam cracker requires 2.7 tons of naphtha per one ton of ethylene production. The summary of data is available in table 3 of this fact sheet as well. Requirements of MTP and MTO are, also, completely discussed at the same report, the fact sheet on the Propylene production [4]. A brief overview of the other routes is explained at following sections.

Production and consumption in Belgium – Ethylene is produced in Belgium by BASF and Total petrochemicals with capacities of $1080*10^3$ and $600*10^3$ t/y respectively [5].

Ethylene Production via Cracking of Ethane-Propane – Ethane is the most favored feedstock for steam cracker due to two key factors. First, ethane production costs are not sensitive to oil price levels, while naphtha-based producers need a lower oil price to remain competitive. Second, ethane-based production requires lower levels of feedstock input compared to naphtha. The ethane requirement of ethane cracker is 1.2 $t/t_{Ethylene}$ ton of ethylene, while around three tons of naphtha is needed to produce a ton of ethylene. The yield of ethylene at ethane based steam cracker is equal to 81% while the yields are 25% and 35% respectively for Gas oil and Naphtha based crackers [6].

The steam-cracking process for ethylene production from an ethane-propane mixture can be divided into three main parts: cracking and quenching; compression; drying, and separation. Figure 1 depicts the process diagram of ethylene-production via the cracking of an ethane-propane mixture [7].

Investment and production costs - Estimated capital expenses to construct the plant for production of ethylene via cracking of ethane-propane are about 2.14 bn $€_{2015}$, while the operating expenses are

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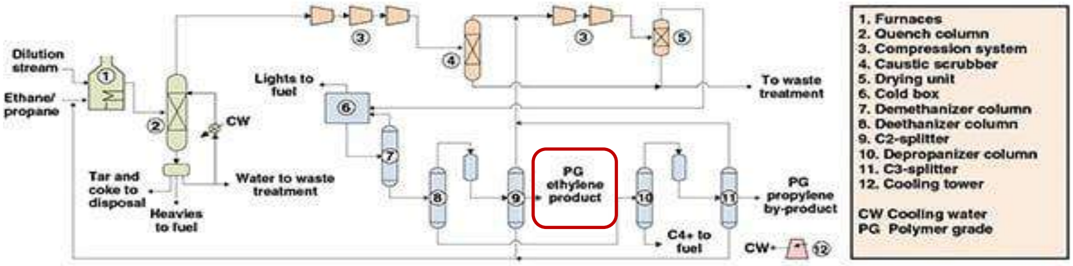

Figure 1. process diagram of ethylene-production process via the cracking of an ethane-propane mixture [7]

Table 1. Required utilities for manufacturing Ethylene from Shale Gas via co-cracking design and technology integrated design [8].

	Co-cracking design	Technology-integrated design
Shale gas processing stage		
power (MW)*	97	139.7
LP steam (125 °C) (GJ/h)*	58.7	165.2
MP steam (175 °C) (GJ/h)*	13.3	17.1
HP steam (250 °C) (GJ/h)*	13.8	17.6
Olefins production stage		
power (MW)*	88.9	142.8
LP steam (125 °C) (GJ/h)*	414	1509
total fuel consumption (GJ/h)	2992	3977
external fuel demand (GJ/h)	1643	3397

* Power and steam are generated on-site

estimated at about 324.32 €$_{2015}$ per ton of produced ethylene [7].

Energy requirements – For the 197.3 t/h ethane−propane mixture as input and Ethylene production from Shale Gas equal to 125 t/h, the required energies are listed as utilities in table 1 [8].

Ethylene yield from MTO and MTP plants - The yield of ethylene at a common MTO plant is 0.4 $kg_{Ethylene}/kg_{Hydrocarbon}$ which is almost equal to the yield of propylene from MTO. However, by changing the process severity the propylene to ethylene ratio can reach values up to up to 2.1 [9]. Besides, Ethylene is one the byproducts at MTP plant with the small share of 0.08 $kg_{Ethyele}/kg_{Propylene}$ while the share of ethylene at naphtha based steam cracker is 2.44 times higher than propylene production [10].

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Oxidative dehydrogenation of ethane to ethylene in an integrated CO_2 capture-utilization process - Al-Mamoori et. al. [11] have studied in-situ capture and utilization of CO_2 in ethylene production through oxidative dehydrogenation (ODH) of ethane. The ODH of ethane occurs at lower temperatures and subsequently at less energy than the steam cracking reaction (30% less energy). Using an appropriate catalyst, ODH can operate at lower temperatures (300–550 °C) than steam crackers. However, there is no commercial technology for ethane catalytic dehydrogenation [12]. Depending on the ODH process conditions and ratio of feedstocks the conversion and selectivity range of the reaction are 57-74% and 62-93% respectively. The specific energy and specific feedstock requirements are, also, in range of 7-13 $kW/kg_{Ethylene}$ and 11-23 $kg_{Ethane}/kg_{Ethylene}$ respectively [13].

Bio-ethylene - Ethylene can be produced from catalytically dehydrated ethanol, in which ethanol can be obtained from various biomass sources such as corn stover. Bio-ethylene can then be used in traditional polyethylene polymerization processes [14]. Moreover, the biomass-derived carbon emissions can be addressed in terms of its carbon neutrality. Basically, the fixed carbon captured by plants during growth should be included as negative emissions with equivalent amounts of emissions through the life cycle [15].

Catalytic dehydration of ethanol - The industrial production of ethylene by catalytic ethanol dehydration has been known since 1913. The ethylene production via fermentation technology is depicted in figure 2 [16].

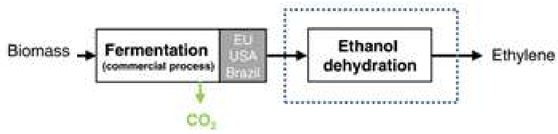

Figure 2. Outline of selected case study and system boundaries [16].

Cost and energy of catalytic dehydration of ethanol - Several ethanol dehydration industrial plants are producing ethylene mainly located in Brazil, in which ethanol is produced via green routes. However, the ethylene production rate via ethanol dehydration is considerably less than its production via steam crackers [17]. In the ethylene production via fermentation technology for processing of 16.9–53.2 $t_{Ethanol}/h$, 4–13 MW electricity and 7–24

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MW natural gas[3] are required and the process yields 9.9–38.9 $t_{Ethylene}/h$ with energy efficiency of 81.8% [16]. The production costs for this case changes at different countries. The specific cost of this process for ethylene production is around 1.7 $€_{2013}/kg_{Ethylene}$ in Europe while it is around 1.2 $€_{2013}/kg_{Ethylene}$ and 1 $€_{2013}/kg_{Ethylene}$ in United States and Brazil respectively [16].

Oxidative coupling of methane - Oxidative coupling of methane (OCM) is a direct route to obtain higher hydrocarbons from natural gas in a single step. OCM involves conversion of methane together with an oxidizing agent at high temperature (>750 °C) into the desired product C_2H_4 (or C_2H_6) and the main undesired by-products CO and CO_2. The yield of higher hydrocarbons (C_2 and higher) is insufficient (≤ 30%) to make the OCM concept industrially feasible, which would require C_{2+} yields above 30–35% [18].

CO_2 emission - Total CO_2 emission from natural gas-to-ethylene process is equal to 2.46 $t_{CO2}/t_{Ethylene}$. The GHG emission of naphtha based cracker is mainly from the process of naphtha and ethylene production, accounting for 26.8% and 57.1% of the total emission; the GHG emission of natural gas based ethylene production is mainly from the processes of natural gas-to-methanol and methanol-to-olefins, accounting for 57.5% and 21.5% of the total emission [19].

Carbon capture and storage (CCS) in Ethylene production – Due to the endothermic nature of the cracking reaction a high combustion duty has to be fired in the cracking furnaces [20]. Ethylene manufacturing facilities are more clustered than any other major CO_2-emitting industry and responsible for a higher proportion than any other major CO_2 emitting industry [21]. The CO_2 emission of ethylene production in the ethane and naphtha cracker are 1-1.2 $t_{CO2}/t_{Ethylene}$ and 1.8-2 $t_{CO2}/t_{Ethylene}$ respectively [6].

Ethylene production for indirect electrification of chemical industry - Ethylene production, using electrochemical-facilitated non-oxidative ethane dehydrogenation, is an emerging, but promising, process to facilitate electrification of the ethylene industry.

[3] Ethanol production energy requirement is not included.

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Ethylene can be produced via low-temperature electrochemical route using solid-oxide membrane reactors/stacks (LoTempLene). The single-pass ethylene yield for the LoTempLene reactor is predicted to be 48.5% by 2025 through optimization of the current state of technology. Furthermore, steam-cracking process emits 1.47 ton of CO_2 per ton of ethylene, compared with 0.4 tons of CO_2 released from the LoTempLene process, resulting in a 72% reduce in CO_2 emission when grid electricity is used versus an 89% reduction when green electricity is used [22].

Yearly estimated total direct CO_2 emissions related to Belgian Ethylene production volume – As it is explained at Propylene production fact sheet, the overview of the specific energy consumptions (SEC) and CO_2 emission for steam cracking is included in table 2 for both feedstocks of ethane and naphtha [6].

Table 2. Overview of energy use and CO_2 emissions of ethane and naphtha steam cracking

Feedstock	SEC		CO_2 emissions	
	($GJ/t_{ethylene}$)	(GJ/t_{HVC})*	($t_{CO2}/t_{ethylene}$)	(t_{CO2}/t_{HVC})
Ethane	17-21 15-25	16-19 12.5-21	1.0-1.2	1.0-1.2
Naphtha	26-31 25-40	14-17 14-22	1.8-2.0	1.6-1.8
Gasoil	40-50	18-23		

* HVC represents high value chemicals

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Table3. Summary Table: Key EO Data and Figures

Main production methods	**Feedstocks**	**Supply percentage (2021)**	**Ethylene yield**
Steam cracker	Ethane	40.1%	80%
	Naphtha	38.0%	30%
	LPG	13.3%	41%*
	Others	8.6%	-
ODH [4]	Ethane	- ***	46% **
MTO	Methanol	- ***	75%–80%
Catalytic dehydration of ethanol[5]	Ethanol	- ***	9.9–38.9 ****
Ethylene production in Belgium			
Overall production rate (t/y)	$1680*10^3$		
Energy and costs	**Electricity**	**Total energy**	**Costs**
Steam cracker	44 (kWh/$t_{Ethylene}$)	120 (GJ/$t_{Ethylene}$)	748 €$_{2017}$ /$t_{Ethylene}$
ODH	7-13 (kW/$kg_{Ethylene}$)	5.09 (GJTh/t_{HVP})	372.57 (€$_{2017}$/ $t_{Ethylene}$)
MTO	-	12–15 (GJ/$t_{Ethylene}$)	588.99 (€$_{2018}$/ $t_{Ethylene}$)
Catalytic dehydration of ethanol	4–13 MW	7–24 MW (natural gas)	2300.88 (€$_{2017}$/$t_{Bio\text{-}Ethylene}$)

* Average value
** The yield can change depending on the catalyst
*** Small portions and included in others (8.6%)
**** Via fermentation process. This value depends on the feedstock and process

[4] Oxidative dehydrogenation of ethane
[5] This route is mainly discussed for green ethylene production

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