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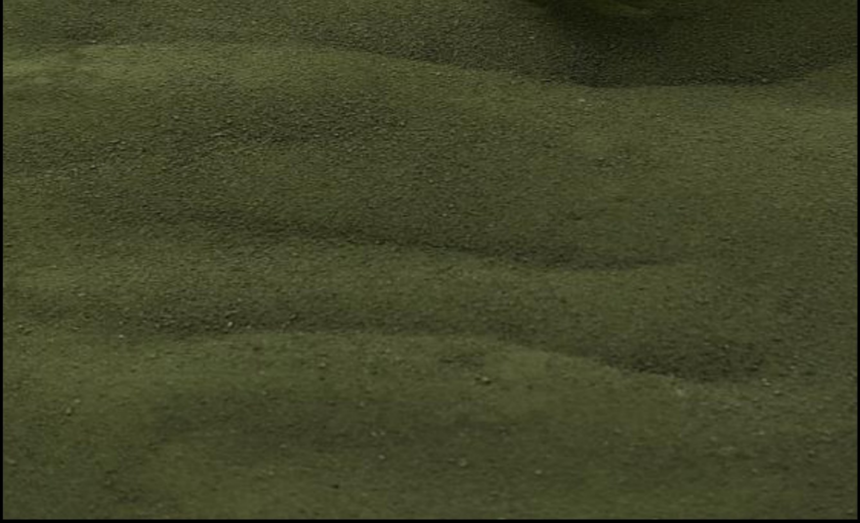
In This Issue

Volume 9 | Number 36

SPECIAL FEATURES



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How to... CHIMNEY TRAY
How to design Chimney Trays

Dr.-Ing. Volker Engel

Chimney Trays (also called „Collector Trays“ or „Draw-Offs“) are not used for mass transfer – but they are important and sometimes also critical components for the operation of columns. This article describes the functions, designs and leakage classes of these trays.

Chimney Trays are used in all kinds of columns for collecting liquid (in order to feed or draw liquid; also called „Draw-Off Tray“ or „Trap-Out Tray“), providing residence time for gas disentrainment, buffering liquid to counteract operational instabilities (also called „Holdup Tray“) as well as for achieving a proper gas distribution (also called „Gas Distribution Tray“). Additionally they may be used for surge volume, buffer against upsets and for two-phase liquid draw.

Fig. 1 shows the set of main functions of a Chimney Tray (blue branch for liquid aspect, red branch for gas aspect).

TYPES OF CHIMNEY TRAYS

In principle a Chimney Tray consists of a sealed layer (base panels) with gas chimneys (normally called „risers“). Depending on the function of the trays, there will be additionally downcomers, troughs, boxes and hats for the risers.

In the following, different types of Chimney Trays are presented.

Total Draw-Off (Total Trap-out)

All liquid is drawn by one or more nozzles (Fig. 2). Due to static reasons and to minimize the total holdup of the tray, there are troughs or boxes at the nozzles for drawing the liquid. If not all liquid can be drawn by the nozzles, the Chimney Tray will flood and the liquid will drain down the risers. This must be taken into account in the design, both in terms of process and statics!

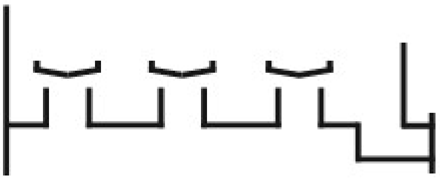


Fig. 2: Total Draw-Off Tray

Partial Draw-Off

Part of the liquid is drawn by one or more nozzles (Fig. 3). The rest of the liquid is transferred to the next stage by downcomer(s).

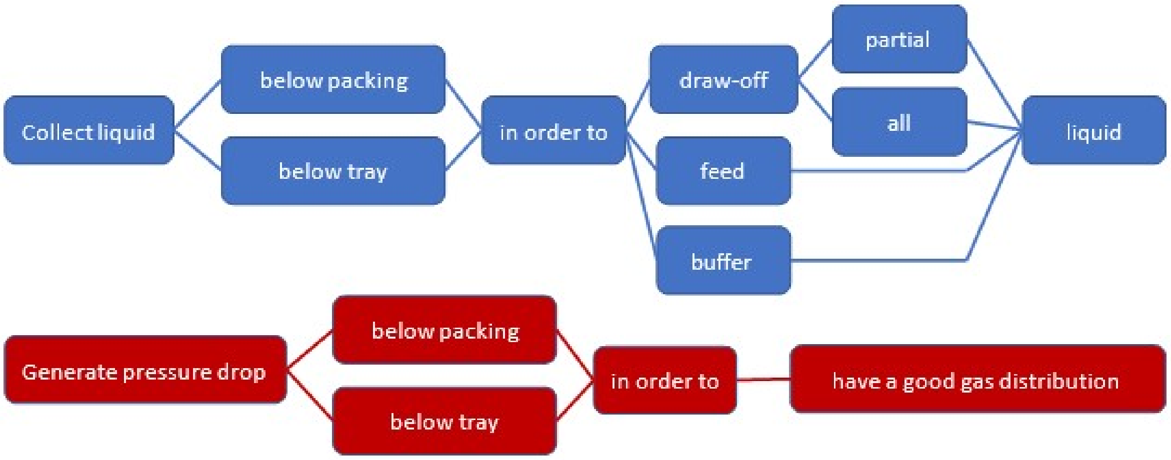


Fig. 1: Functions of Chimney Trays

Fig. 3: Partial Draw-Off Tray

No Draw-Off

All liquid is transferred to the next stage by downcomers (Fig. 4). These downcomers may be designed as classical downcomers for multi - pass trays or as multi-downcomers as boxes on the entire cross-sectional area. This type is used for improving the gas distribution as well as to add a feed and mix it with the liquid of the current stage.

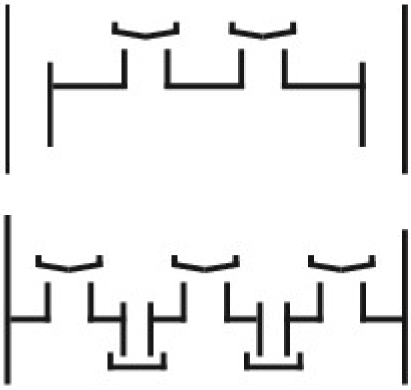


Fig. 4: No Draw-Off

TYPES OF RISERS

The design of the risers is adapted to the functionality of the Chimney Tray.

Number and size of risers: For gas distribution, there will be many small risers spread over the total cross-sectional area. When there is no issue for gas distribution, few risers are realized (Fig. 5). The dimension of the riser has to take care about the size of the manhole.

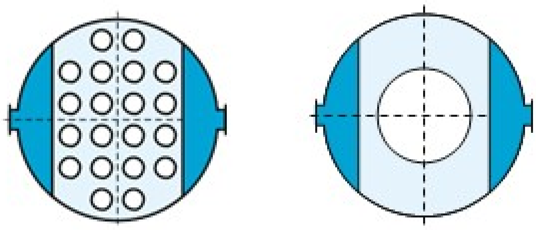


Fig. 5: Number and size of risers

Height of risers: Risers have to be higher than any weir on the Chimney Tray in order to have no overflow through the risers!

Shape of risers: When there is need for many small risers, normally round risers built from pipe material are used.

For static reasons rectangular risers are the preferred shape (Fig. 6). To utilize the entire area of a chimney tray, there may be trapezoid risers as well..

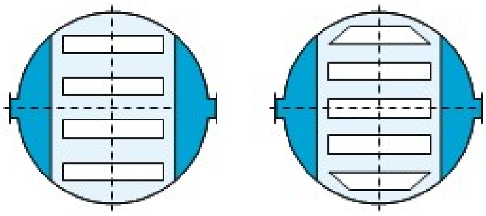


Fig. 6: Rectangular risers

Hats of risers: To prevent liquid falling through a riser (e.g. if a Chimney Tray is located below a packing section), the risers are equipped with hats (roofs). The hats are normally bended and protrude the riser area, so that the liquid from the hat can not run into the riser (Fig. 7).

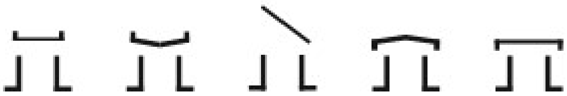


Fig. 7: Shape of risers' hats

To support the liquid flow towards the draw-offs, the rectangular hats can be sloped (Fig. 8). The construction has to ensure, that no liquid will flow in the riser.

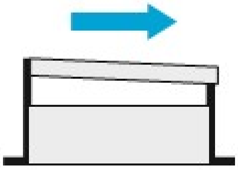


Fig. 8: Sloping of hats

For generating a certain pressure drop (in case of using the Chimney Tray as gas distribution device) one can reduce the outlet area by adjusting the distance of the hat to the riser.

Because by this a high gas outlet velocity is induced (not helpful for optimal gas distribution), it is more practical to generate the pressure drop by inlays (Fig. 9). These inlays are slotted panels to achieve a certain pressure drop.

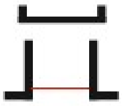
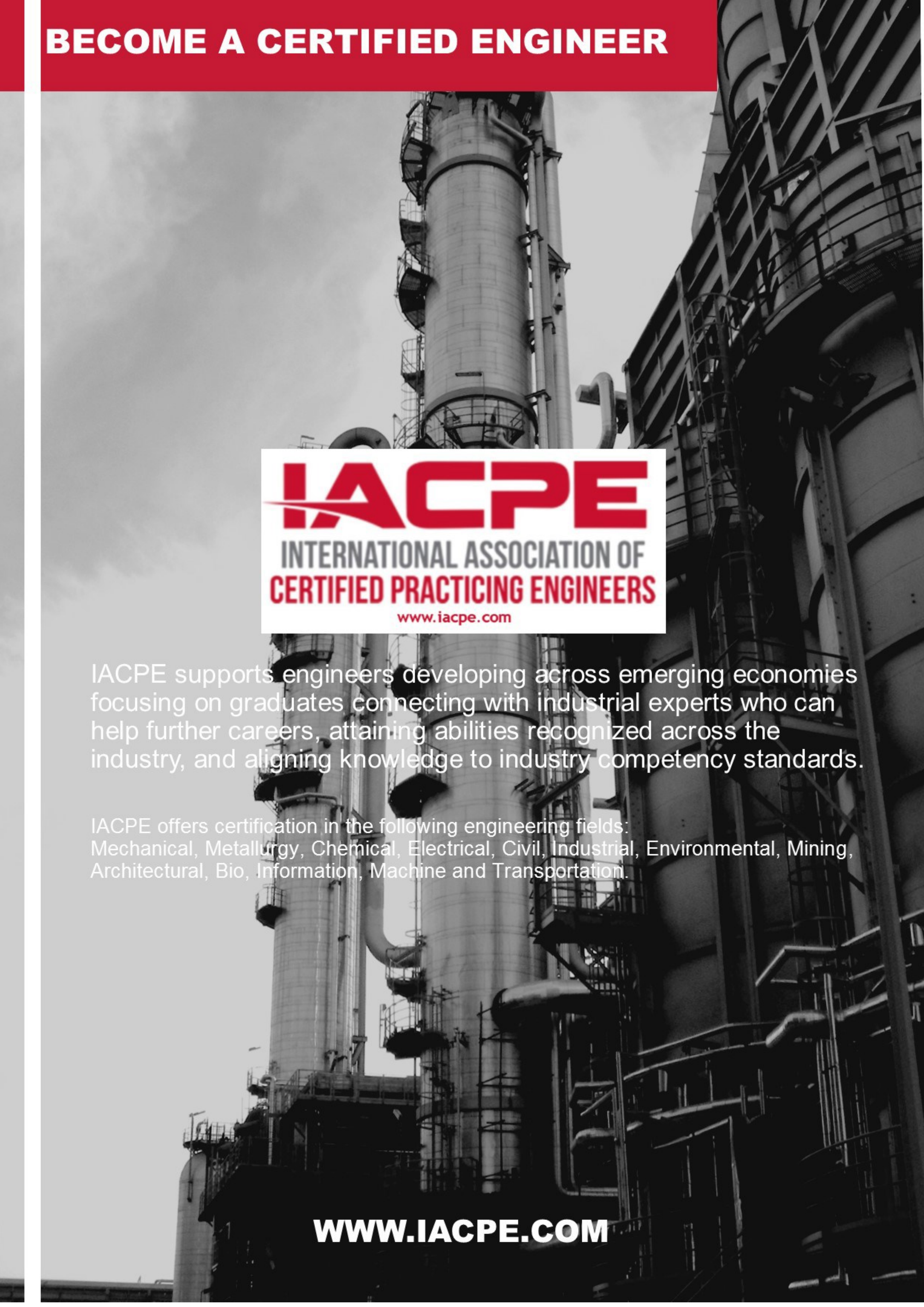


Fig. 9: Inlay in riser



TYPES OF DOWNCOMERS

As for classical trays, there are single and multi- pass designs for the downcomers. Especially when the stage below is a trayed section, the downcomer positions and dimensions are set by this design.

For the case of a liquid distributor below the Chimney Tray, the liquid has to be transferred to the pre-distribution box(es). In this case, the downcomer position has to be harmonized with the pre-distribution troughs. For large-scale distributors, there may be used multi-DCs. In this case, sometimes inlays are used for

reducing the liquid inlet impulse to the pre- distribution throughs.

HYDRAULICS: PRESSURE DROP

For the Chimney Tray mainly acting as liquid collector, the open area of the risers should be large and therefore the pressure drop low. For those applications the pressure drop will be about or less than 0.1 mbar. If the Chimney Tray is located within a trayed section, the open area is normally about 10 percentage points larger than the open area of the trays.

When the Chimney Tray is built for gas distribution, the tray has to have a noticeable pressure drop. For good functionality, the pressure drop – even at minimum gas load – should be about 1 mbar (depends on the operational pressure of the tower).

The pressure drop is calculated by Eq. 1. It is the standard correlation (Darcy‘s law) for pressure drop through openings where the friction factors K_i describe the change of the velocity and direction of the gas by passing the riser.

$$\Delta p = C \cdot \rho_G \cdot w_G^2 \cdot \sum_i K_i \qquad \text{(Eq. 1)}$$

HYDRAULICS: SYSTEM FLOOD

Whenever the Chimney Tray is located below a packing and gas is flowing in counter current (e.g. to the liquid from the support grid), System Flood FFSF has to be checked.

The FFSF calculation checks, whether liquid droplets can fall down when gas is streaming upwards. When the droplets are carried upwards, no counter flow will be possible anymore and the column will flood. This flooding has to be checked for the least cross- sectional area, where gas and liquid have to pass. If there are hats on the risers, the open area between the hats is normally the smallest area. If flooding in this area is indicated, the tower may still work, because liquid can drain by the risers‘ hats. But one has to ensure, that this draining is optimized and without any contact with gas.

HYDRAULICS: DOWNCOMER

On a Chimney Tray the classical Choke Flood (FFCF) calculation models are not applicable, since there is no froth layer entering the downcomers. There is no or only little degassing of liquid in the downcomer. Therefore the downcomer area is normally not checked for choke flood, but by criteria of self-venting flow.

Another flooding mechanism for downcomers is the Aerated Downcomer Backup Flood (FFAF). All contributing effects to the downcomer backup have to be calculated: (a) Pressure drop of the Chimney Tray, (b) liquid head by the clearance of the downcomers, (c) weir height and weir crest height of a seal pan. Since the pressure drop of a Chimney Tray is normally not high, there is no problem to keep the downcomer level within moderate values. But for gas distribution applications, the effect has to be considered very carefully (especially for maximum load).

If there is any risk of pressure surges from the section below the Chimney Tray, the liquid level in the downcomers has to be designed to be sufficient (sealing by high seal pan or inlet weir) to prevent gas channeling the downcomer.

CONSTRUCTION: THERMAL EXPANSION

Chimney Trays are often welded-in in order to achieve a high degree of tightness. It is essential to ensure that the construction can absorb any thermal expansion that may occur!

This thermal stress occurs, when the column is heated or cooled because of the different thermal expansion by the very different material parameters (CS, SS, alloy) and different material thickness of tray panels and tower shell.

Fig. 10 shows a welded design for small diameters and ambient temperature, where no thermal expansion occurs.

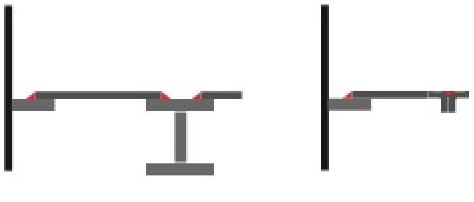


Fig. 10: Construction without thermal compensation

Fig. 11 shows an adapted design for compensating thermal expansion. This is done by using the structural properties of troughs (a) or bendings (b).

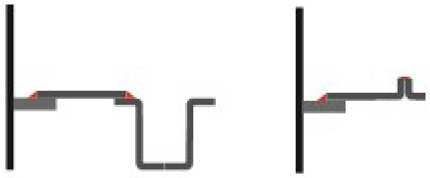


Fig. 11: Construction without compensation

Another common idea to structurally separate the Chimeny Tray from the column hardware is to use half pipes (at the support ring as well as at major beams).

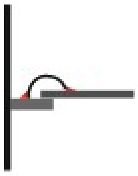


Fig. 12: Half-pipe for thermal compensation

For bolted and gasketed constructions (Fig. 13), the thermal expansion is normally not an issue. But those types will not achieve a high leakage class due to remaining openings. It is important to have a narrow clamp spacing and to use gasket washers for all boltings.

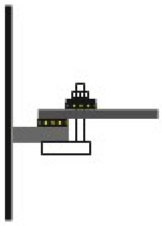


Fig. 13: Bolted design

CONSTRUCTION: STATICS

The maximum level of liquid results from the risers' height or from the weir height of the downcomers (if there are any). This level of liquid has to be taken into account for statics.

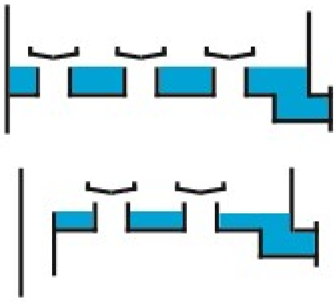


Fig. 14: Level of liquid

For total draw-off designs with small risers the maximum level might be even higher (e.g. when the risers are not able to drain the total amount of liquid in case of draw-off failure).

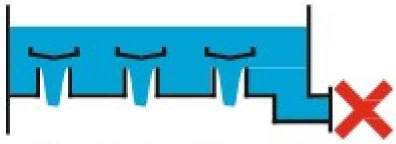


Fig. 15: Overfilling of trays

To achieve proper statics, troughs are often used as base. In this case, the troughs are fabricated as tower attachments.

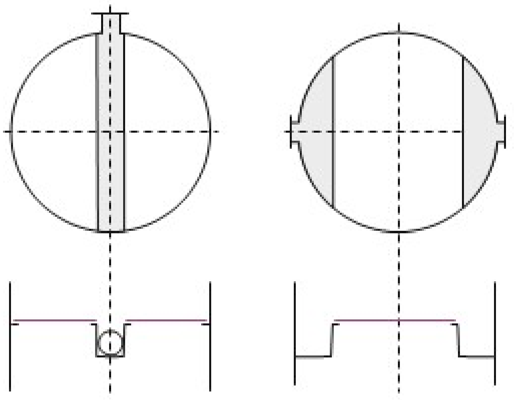


Fig. 16: Statics of Chimney Trays

In case of a classical tray construction setup, the construction is based on a support ring and major beam(s).

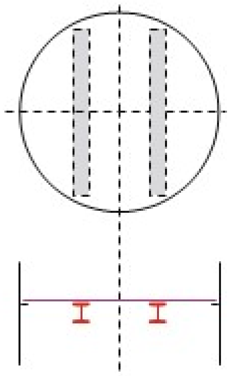


Fig. 17: Statics by major beams

LEAKAGE CLASSES

Depending on the function of the Chimney Trays, a certain leakage class has to be achieved. Although there is no official set of rules, the following classes are used internationally:

Tightness class 1: For low process requirements max. leakage rates of 0.13 m³/m²/h are accep- ted (Drop of liquid level < 130 mm/h).

Tightness class 2: For medium process require- ments (e.g. Chimney Trays in vacuum towers) a leakage rate of less than 0.06 m³/m²/h has to be achieved (Drop of liquid level < 60 mm/h).

Tightness class 3: For high process requirements (Chimney Trays above packed distillation sec- tion, above packed or trayed flash and scrubbing section in vacuum and atmospheric towers) leakage rates of less than 0.02 m³/m²/h are necessary (Drop of liquid level < 20 mm/h).

Note 1: The cited „drop of liquid level“ depends on the total level of filling. Due to Toricelli‘s law the liquid through an opening depends on the liquid head of the outlet! For measuring a certain leakage class, a proper test scenario has to be defined!

Note 2: It is difficult to have bolted and gasketed manways in the deck at high tightness classes.

Note 3: The best way to achieve a manway in a liquid tight design is to use risers as passage way.

CONCLUSION

As the Chimney Tray is not used for mass transfer, its importance is sometimes underestimated. The failure of a Chimney Tray normally stops the operation of the column. Accordingly, the correct and robust design of these trays is very important.

AUTHOR

Volker Engel studied process engineering at the Technical University of Munich and did his Ph.D. thesis on packed columns with Prof. Johann G. Stichlmair. Since 1998 he has been the managing director of WelChem Process Technology GmbH and head of the TrayHeart software. TrayHeart has developed into a state-of-the-art design tool for trays and internals in process technology.

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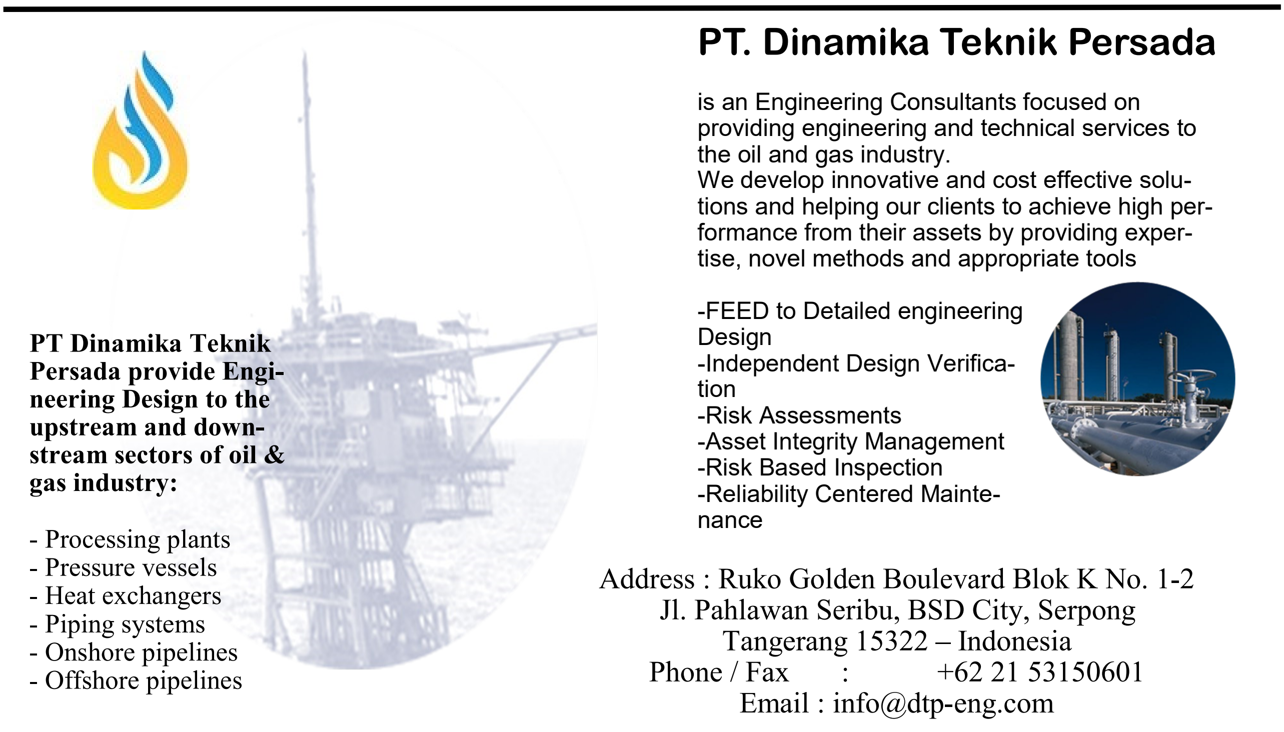


Empirical Approach to Hydrate Formation in Natural Gas Pipelines

Jayanthi Vijay Sarathy

Natural Gas Pipelines often suffer from production losses due to hydrate plugging. For an effective hydrate plug to form, factors can vary from pipeline operating pressure and temperature, presence of water below its dew point, extreme winter conditions & Joule Thomson cooling. In the event hydrates form in the pipeline section, their consequence depends on how well the hydrates agglomerate to grow and form a column. If the pipeline section temperature is only at par with the hydrate formation temperature, the particles do no agglomerate; instead they have to cross the metastable region which is of the order of 50C to 60C, before hydrate formation accelerates to block the pipeline.

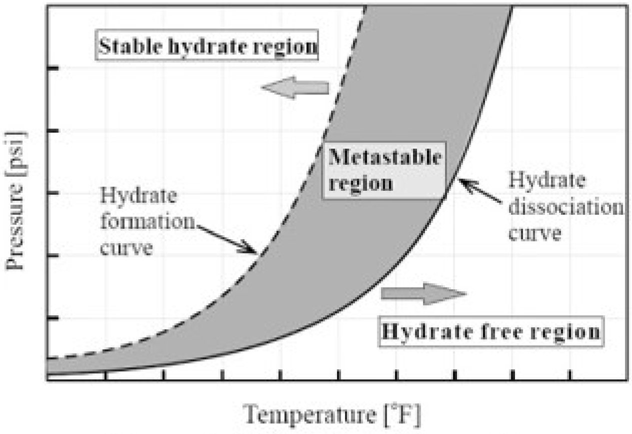


Figure 1. P-T Hydrate Curve [1]

Although engineering softwares exist to estimate pipeline process conditions and also generate a P-T hydrate curve, the following article provides a guidance summary to estimate the expected pipeline temperature profile and the associated hydrate formation temperatures.

PROBLEM STATEMENT

A DN 14”, 20 km hydrocarbon line carrying natural gas at the rate of 85,000 kg/h, 40 bara and 250C is fed to a receiving station. The total pipeline pressure drop per km [DP/km] is taken to be 1 bar/km. The overall heat transfer coefficient is taken to be 25 W/m2.K. The ambient temperature is 120C. The hydrate formation temperature for the composition is experimentally estimated to be 500F at 325 psia. It is required to estimate the pipeline exit A DN 14”, 20 km hydrocarbon line carrying natural gas at the rate of 85,000 kg/h, 40 bara and 250C is fed to a receiving station. The total pipeline pressure drop per km [DP/km] is taken to be 1 bar/km. The overall heat transfer coefficient is taken to be 25 W/m2.K. The ambient temperature is 120C. The hydrate formation temperature for the composition is experimentally estimated to be 500F at 325 psia. It is required to estimate the pipeline exit temperature & the hydrate formation temperature along the pipeline. For the estimates, the Joule-Thomson coefficient is assumed to be an average of 0.560C/bar throughout the pipeline. The natural gas composition is as follows,

Table 1. Gas Mixture [GPSA, Sec 20, Page 20-15]

Component	Mol%	MW [M_i]	y_iM_i
	[%]	[kg/kmol]	[-]
Methane	78.40	16.04	12.58
Ethane	6.00	30.07	1.80
Propane	3.60	44.01	1.58
i-Butane	0.50	58.12	0.29
n-Butane	1.90	58.12	1.10
CO_2	0.20	44.01	0.09
N_2	9.40	28.01	2.63
Total	100.00	**MW [kg/kmol]**	**20.08**

METHODOLOGY

The pipeline temperature profile can be estimated based on Coulter & Bardon (1979) correlation [4]. The steady state temperature profile is calculated from the momentum equation, while omitting the potential & kinetic energy terms in the enthalpy equation.

$$\frac{dh}{dL}+\frac{dQ}{dL}=0 \qquad (1)$$

Where,

$$Q = \frac{\pi \times OD \times U \times \Delta L}{m}[T_0 - T_s] \qquad (2)$$

$$dh = c_p dT - \mu c_p dP \qquad (3)$$

Where,
U = Overall HTC [W/m^2.K]
ID = Pipeline OD [m]
m = mass flow rate [kg/s]
DL = Pipeline length [m]
T_0 = Fluid Temperature [K]
T_s = Surrounding Temperature [K]
m = Joule-Thompson Coefficient [^{0}C/bar]
C_p = Specific heat capacity [J/kg.K]
g_g = Gas Specific Gravity, MW/28.9625 [-]

Solving for pipeline temperature profile,

$$T[L] = \left[T_0 - T_s - \left(\frac{\mu}{a}\right)\left(\frac{dP}{dL}\right)\right]e^{-aL} + T_s + \left(\frac{\mu}{a}\right)\left(\frac{dP}{dL}\right)$$
(4)

Where,

$$a = \frac{\pi \times OD \times U}{m \times C_p}$$

It is to be noted that the specific heat [C_p] and Joule-Thompson [J-T] co-efficient [m] varies with the pipeline pressure & temperature. But for computational purposes, is assumed to be constant. The purpose of including the J-T co-efficient is to account for cooling during gas expansion along the pipeline. The ideal mass specific heat [C_p], kJ/kg.K, of natural gas can be computed as,

$$C_p = \left[(-10.9602\gamma_g + 25.9033) + (0.21517\gamma_g - 0.068687)T + (-0.00013337\gamma_g) + 0.000086387)T^2 + (0.000000031474\gamma_g) - 0.000000028396)T^3\right] / MW(5)$$

Where, T = Temperature [K]

HYDRATE FORMATION TEMPERATURE

To estimate the hydrate formation temperature [Th], Towler & Mokhatab (2005) [3], proposed the following correlation,

$$T_h[°F] = [13.47 \times ln(P)] + [34.27 \times ln(\gamma)] - [1.675 \times ln(P) \times ln(\gamma)] - 20.35 \qquad (6)$$

Where,
P = Pressure [psia]

The validity of the above expression is for the

1. Temperature Range: 260 K to 298 K
2. Pressure Range: 1200 kPa to 40,000 kPa
3. MW: 16 g/mol to 29 g/mol (0.55 < g_g < 1.0)

RESULTS

Substituting the values to arrive at the pipeline temperature profile, the gas specific gravity is estimated as,

ANNEXURE: MS-EXCEL SPREADSHEET

$$\gamma_g = \frac{20.08}{28.9625} = 0.6933 \qquad (7)$$

$$a = \frac{\pi \times \left[\frac{14 \times 25.4}{1000}\right] \times 25}{\left[\frac{85{,}000}{3600}\right] \times 2.071 \times 1000} = 0.0005711 \qquad (8)$$

$$T[L] = 12.0195 \times e^{-0.0005711 \times L} + 286.1305 \qquad (9)$$

The hydrate formation temperature [T_h] is,

$$T_h[°F] = [14.0835 \times ln(P, psi)] - 32.9023 \qquad (10)$$

Plotting the above expressions, we get,

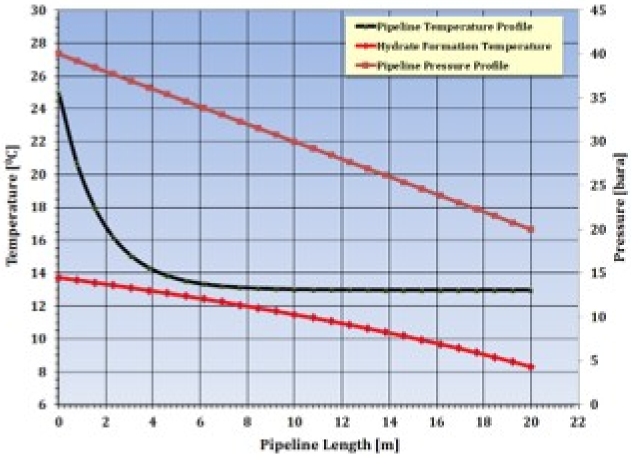
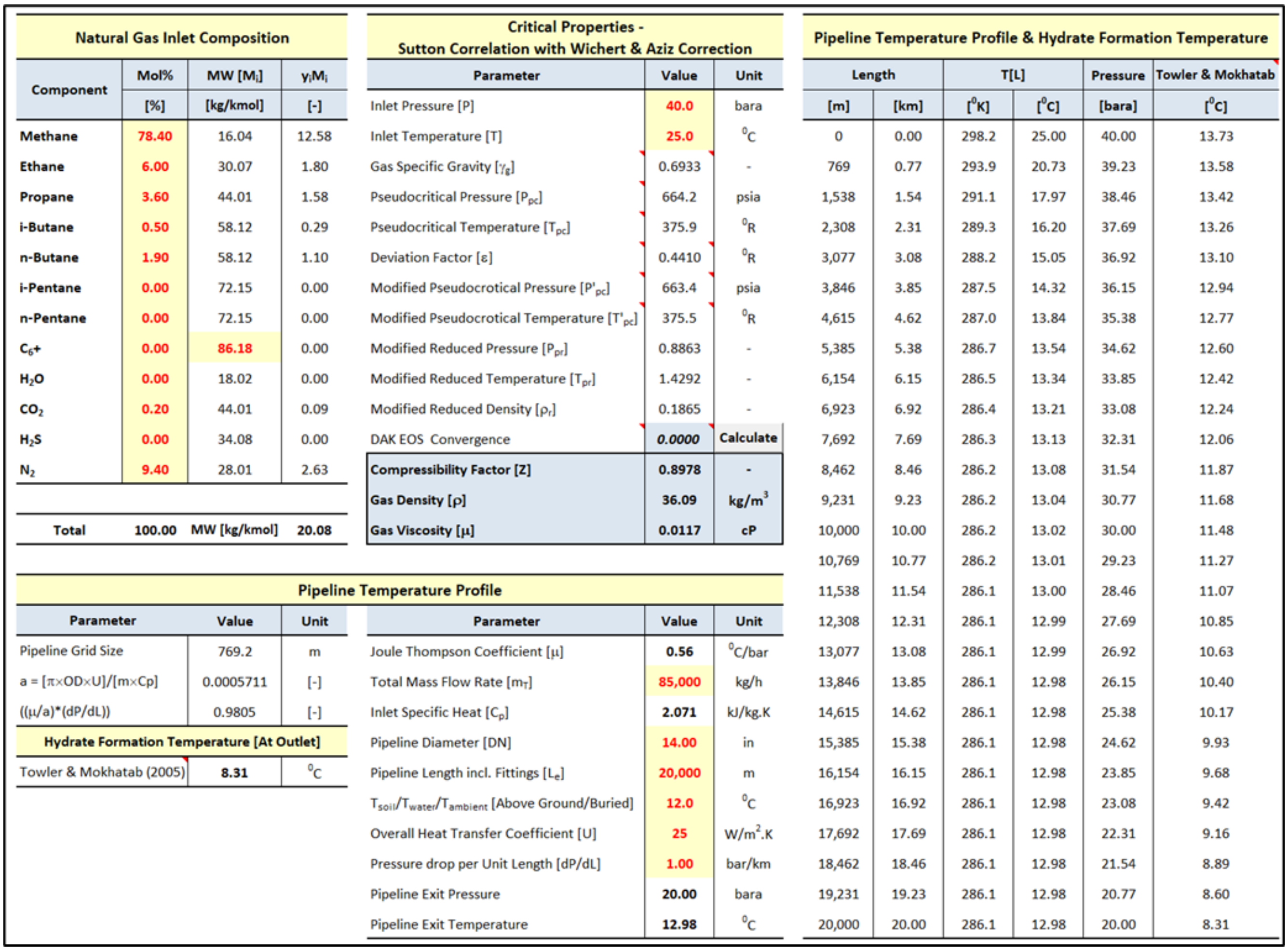


Figure 2. Hydrate Formation Temperature

From the plot, the pipeline temperature stays above the hydrate formation temperature. In practice, to increase the difference, the inlet gas can be either heated or hydrate inhibitors such as MeOH, MEG or TEG can be added.



Natural Gas Inlet Composition

Component	Mol% [%]	MW [M_i] [kg/kmol]	y_iM_i [-]
Methane	78.40	16.04	12.58
Ethane	6.00	30.07	1.80
Propane	3.60	44.01	1.58
i-Butane	0.50	58.12	0.29
n-Butane	1.90	58.12	1.10
i-Pentane	0.00	72.15	0.00
n-Pentane	0.00	72.15	0.00
C_6+	0.00	86.18	0.00
H_2O	0.00	18.02	0.00
CO_2	0.20	44.01	0.09
H_2S	0.00	34.08	0.00
N_2	9.40	28.01	2.63
Total	100.00	MW [kg/kmol]	20.08

Critical Properties - Sutton Correlation with Wichert & Aziz Correction

Parameter	Value	Unit
Inlet Pressure [P]	40.0	bara
Inlet Temperature [T]	25.0	°C
Gas Specific Gravity [γ_g]	0.6933	-
Pseudocritical Pressure [P_{pc}]	664.2	psia
Pseudocritical Temperature [T_{pc}]	375.9	°R
Deviation Factor [ε]	0.4410	°R
Modified Pseudocrotical Pressure [P'_{pc}]	663.4	psia
Modified Pseudocrotical Temperature [T'_{pc}]	375.5	°R
Modified Reduced Pressure [P_{pr}]	0.8863	-
Modified Reduced Temperature [T_{pr}]	1.4292	-
Modified Reduced Density [ρ_r]	0.1865	-
DAK EOS Convergence	*0.0000*	Calculate
Compressibility Factor [Z]	**0.8978**	**-**
Gas Density [ρ]	**36.09**	**kg/m³**
Gas Viscosity [μ]	**0.0117**	**cP**

Pipeline Temperature Profile

Parameter	Value	Unit
Pipeline Grid Size	769.2	m
a = [π×OD×U]/[m×Cp]	0.0005711	[-]
((μ/a)*(dP/dL))	0.9805	[-]
Hydrate Formation Temperature [At Outlet]		
Towler & Mokhatab (2005)	**8.31**	°C

Parameter	Value	Unit
Joule Thompson Coefficient [μ]	**0.56**	°C/bar
Total Mass Flow Rate [m_T]	85,000	kg/h
Inlet Specific Heat [C_p]	**2.071**	kJ/kg.K
Pipeline Diameter [DN]	14.00	in
Pipeline Length incl. Fittings [L_e]	20,000	m
$T_{soil}/T_{water}/T_{ambient}$ [Above Ground/Buried]	12.0	°C
Overall Heat Transfer Coefficient [U]	25	W/m².K
Pressure drop per Unit Length [dP/dL]	1.00	bar/km
Pipeline Exit Pressure	**20.00**	bara
Pipeline Exit Temperature	**12.98**	°C

Pipeline Temperature Profile & Hydrate Formation Temperature

Length [m]	Length [km]	T[L] [°K]	T[L] [°C]	Pressure [bara]	Towler & Mokhatab [°C]
0	0.00	298.2	25.00	40.00	13.73
769	0.77	293.9	20.73	39.23	13.58
1,538	1.54	291.1	17.97	38.46	13.42
2,308	2.31	289.3	16.20	37.69	13.26
3,077	3.08	288.2	15.05	36.92	13.10
3,846	3.85	287.5	14.32	36.15	12.94
4,615	4.62	287.0	13.84	35.38	12.77
5,385	5.38	286.7	13.54	34.62	12.60
6,154	6.15	286.5	13.34	33.85	12.42
6,923	6.92	286.4	13.21	33.08	12.24
7,692	7.69	286.3	13.13	32.31	12.06
8,462	8.46	286.2	13.08	31.54	11.87
9,231	9.23	286.2	13.04	30.77	11.68
10,000	10.00	286.2	13.02	30.00	11.48
10,769	10.77	286.2	13.01	29.23	11.27
11,538	11.54	286.1	13.00	28.46	11.07
12,308	12.31	286.1	12.99	27.69	10.85
13,077	13.08	286.1	12.99	26.92	10.63
13,846	13.85	286.1	12.98	26.15	10.40
14,615	14.62	286.1	12.98	25.38	10.17
15,385	15.38	286.1	12.98	24.62	9.93
16,154	16.15	286.1	12.98	23.85	9.68
16,923	16.92	286.1	12.98	23.08	9.42
17,692	17.69	286.1	12.98	22.31	9.16
18,462	18.46	286.1	12.98	21.54	8.89
19,231	19.23	286.1	12.98	20.77	8.60
20,000	20.00	286.1	12.98	20.00	8.31

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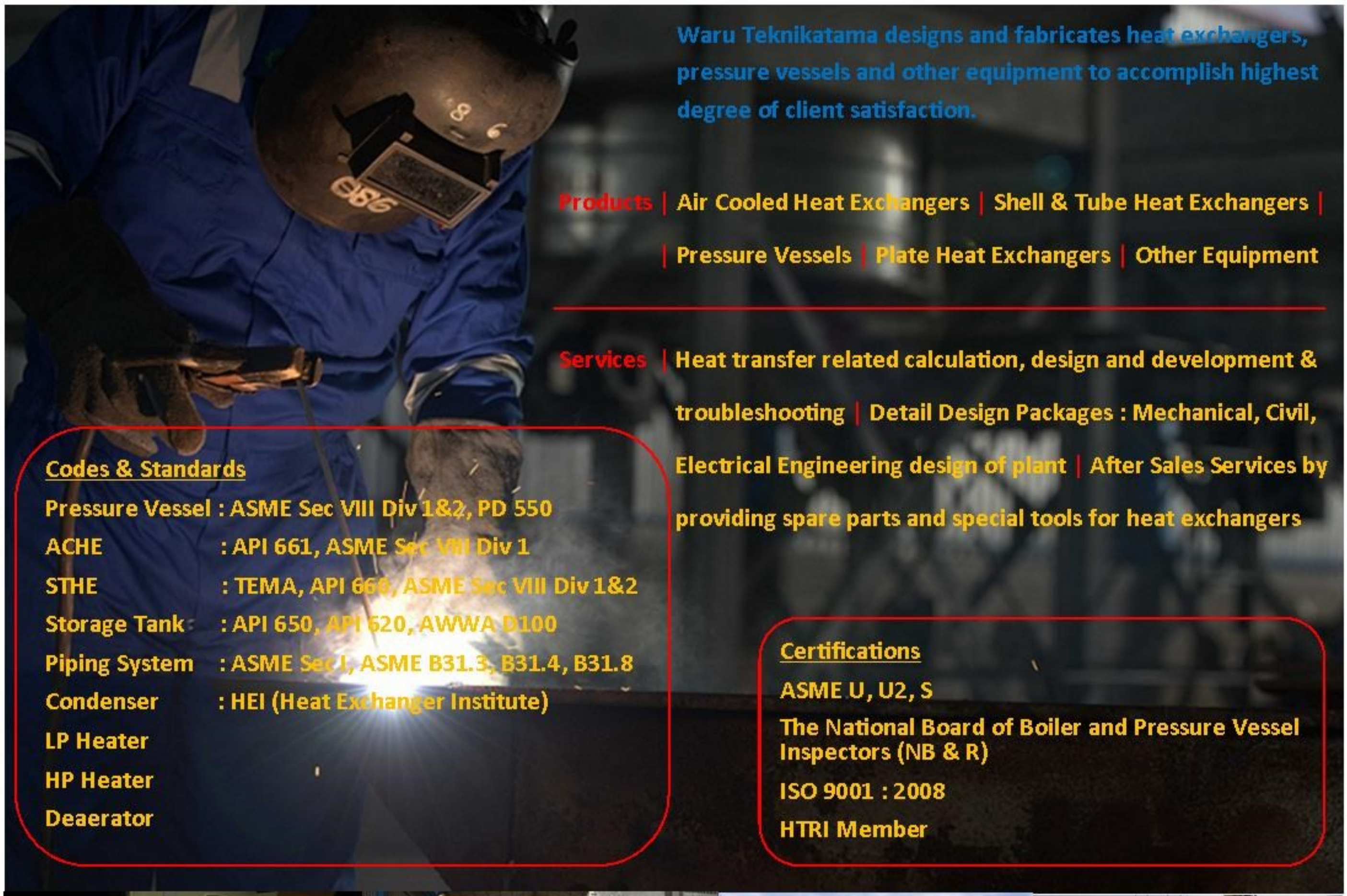

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Why the Energy Transition in the Downstream Industry Pass Through Renewable Hydrogen?

Dr. Marcio Wagner da Silva

INTRODUCTION AND CONTEXT

Demand for hydrogen raised strongly in the last decades following the necessity of hydrotreatment units installations in refineries to comply with the pressure to reduce the content of contaminants like sulfur and nitrogen in the petroleum derivates and consequently minimizing the environmental impact caused by fuels burn.

Given the greater offer of natural gas in the last years, the hydrogen generation process through Methane (main natural gas component) reforming reactions has consolidated like the principal route to produce hydrogen and syngas to the production of the most diversified chemical products like ammonia and conversion of methanol to olefins (MTO processes), etc.

Regarding the hydrogen, this compound became a fundamental enabler to the crude oil refining chain. Due to the increasingly necessity to reduce the environmental impact of the crude oil derivatives, it’s practically impossible to produce marketable crude oil derivatives without at least one hydroprocessing step, raising the hydrogen demand as aforementioned. In this sense, even to efforts related to energy transition by the downstream industry, the hydrogen presents a key role.

As aforementioned, hydrogen is a key enabler to the future of the downstream industry and the development of renewable sources of hydrogen is fundamental to the success of the efforts to the energy transition to a lower carbon profile. According to the Wood Mackenzie data the green and blue hydrogen generation routes tends to take-off in the next years, these data are presented in Figure 1.

In the current scenario, the best alternative to refiners is optimize the hydrogen consumption minimizing the operating costs and CO2 emissions.

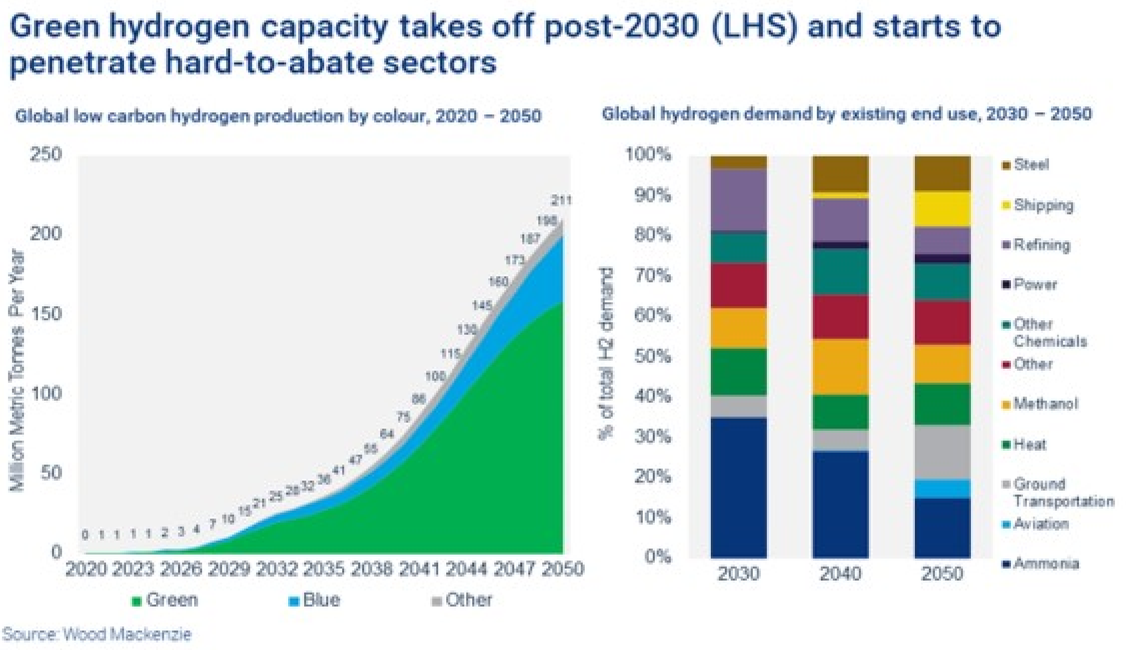


Figure 1 – Evolution of the Cleaner Hydrogen Production Routes (Wood Mackenzie, 2020)

HYDROGEN AND SYNGAS PRODUCTION ROUTES - INTRODUCTION

Methane steam reforming is currently the most employed technology to produce syngas and hydrogen, moreover, it's presented at the moment as the most economical route to produce hydrogen in large scale.

The methane steam reforming process can be chemically represented like presented below:

$CH_4 + H_2O = CO + 3H_2$
(Steam Reforming Reaction - Endothermic)
$CO + H_2O = CO_2 + H_2$
(Shift Reaction - Exothermic)

The reforming reaction is endothermic, so is favored by higher temperatures (700 – 850 ^{o}C) and the catalyst commonly employed is a catalyst with a high content of nickel (Ni) over alumina (Al_2O_3). The reaction equilibrium is favored by lower pressures, however, to avoid the necessity of produced gasses compression the reactions are conducted under moderate pressures (15 – 25 bar).

Shift reaction is slightly exothermic and occurs under mild reaction conditions (200 – 350 ^{o}C) over iron oxide catalyst promoted with cobalt and copper.

Figure 2 shows a basic arrangement for process unit dedicated to producing hydrogen by Methane steam reforming.

Once the nickel catalyst is strongly sensitive to contaminants like sulfur that can cause his deactivation, in the process have a treatment step dedicated to removing these contaminants from methane stream.

Some undesired reactions can occur during the methane steam reforming process conducting the coke deposition over the catalyst leading to loss of chemical activity or a complete deactivation, as described below:

$2\ CO = C + CO_2$
(Boudouard Reaction)
$CH_4 = C + 2\ H_2$
(Methane Thermal Decomposition)
$CO + H_2 = C + H_2O$
(CO Reduction)

To minimize the risk of carbon deposits, the process is conducted with higher steam/hydrocarbon ratio (3 – 4 mole of H_2O per carbon mole), however, the steam/hydrocarbon ratio can't be much high because can lead to excessive dimensions of the process equipment and the lower H_2O/hydrocarbon ratio can be compensated by temperature rising. Another side effect of the rise of H_2O/hydrocarbon ratio is the CO reduction that changes the CO/H_2 ratio. Figure 3 presents a basic process flow diagram for a hydrogen generation unit through natural gas steam reforming by Haldor Topsoe Company.

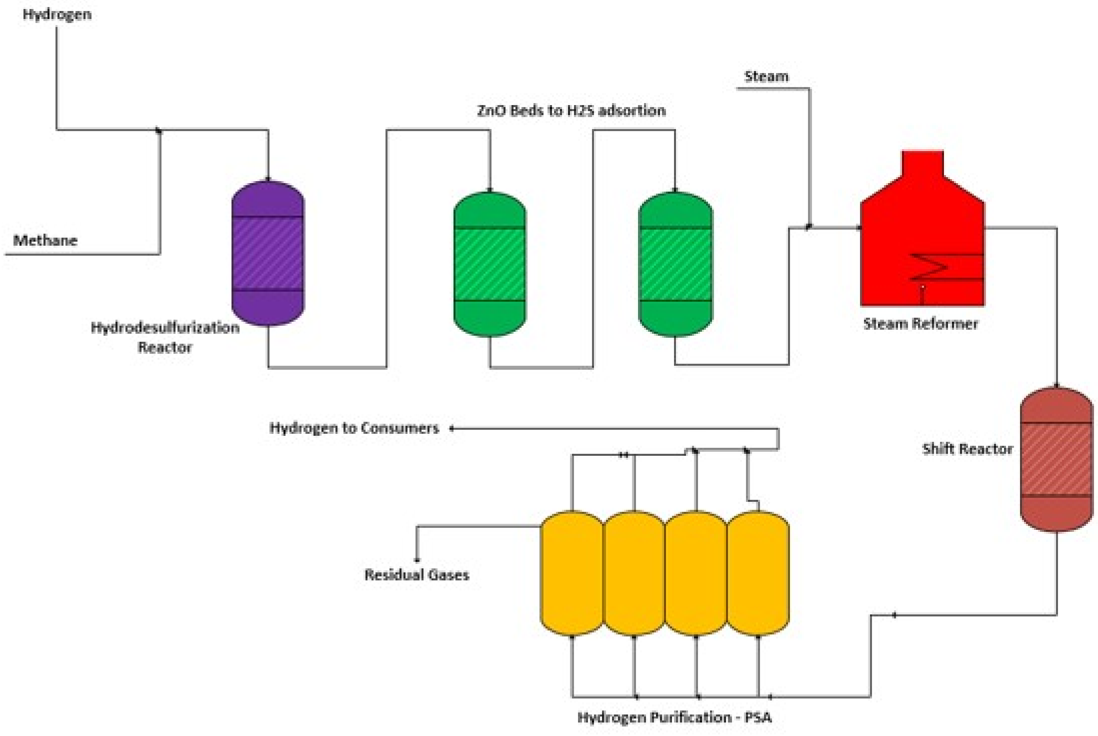


Figure 2- Basic Process Flow Scheme for Methane Steam Reforming Process

Another much-studied technology aiming to the hydrogen production is called methane dry reforming, the principal chemical reaction of the dry reforming process is presented below:

$CH_4 + CO_2 = 2CO + 2H_2$
(Methane Dry Reforming Reaction)

Methane dry reforming reaction is endothermic and conducted under high temperatures (higher than 700 °C) over a nickel-based catalyst. The dry reforming production route is attractive from the environment point of view because can minimize the water consumption and the main reagent is a combustion subproduct that is partially responsible for the greenhouse effect. Another point in favor of dry reforming technology is that the syngas from this process had the ratio $H_2/CO = 1$, this characteristic is ideal for producing oxygenated compounds as acetic acid and dimetilic ether.

Meanwhile, the main challenge to be overcome to the development of the dry reforming technology is the strongly tendency to coke deposition over the catalysts. Due to the nonexistence of water in the process and the low H/C ratio in the process feed, the coke formation over the catalysts applied in the dry reforming process is much severe.

Several researchers had studied ways to develop more resistant catalysts against deactivation by carbon deposition to provide practical application for methane dry reforming technology. Another point to be considered in the dry reforming process development is the necessity of CO_2 purification that can contribute in a negative form to the economic viability of the process when compared with the steam reforming process.

Methane Partial Catalytic Oxidation Process shows attractive once produces syngas with $H_2/CO = 2$, that's ideal for Fischer-Tropsch synthesis. The main chemical reaction in the methane partial catalytic oxidation process is presented below:

$CH_4 + \frac{1}{2} O_2 = CO + 2 H_2$
(Partial Oxidation – Exothermic)

This technology applies nickel based catalysts, however, some research was developed using platinum, palladium, rhodium and ruthenium as active metals, despite the higher cost of these metals when compared with the nickel.

The presence of oxygen in the process reduces the carbon deposit formation over the catalyst, but the use of pure oxygen is not economically competitive because needs the installation of cryogenic separation unit to separate the oxygen from air, on the other hand, using air in the process would increase the equipment dimensions due to the N2 presence. Another problem associated with methane partial oxidation is related to the safety owing to the process feed is a mixture of CH_4 and O_2 that can present explosion risk under some process conditions.

Another promising technology to produce syngas and hydrogen from methane is called Autothermal Reforming Process. This technology is target of several studies and is basically a combination of partial oxidation and steam reforming processes, the principal reactions involved in this process are showed below:

$CH_4 + 1 \frac{1}{2} O_2 = CO + 2 H_2O$
(Exothermic)

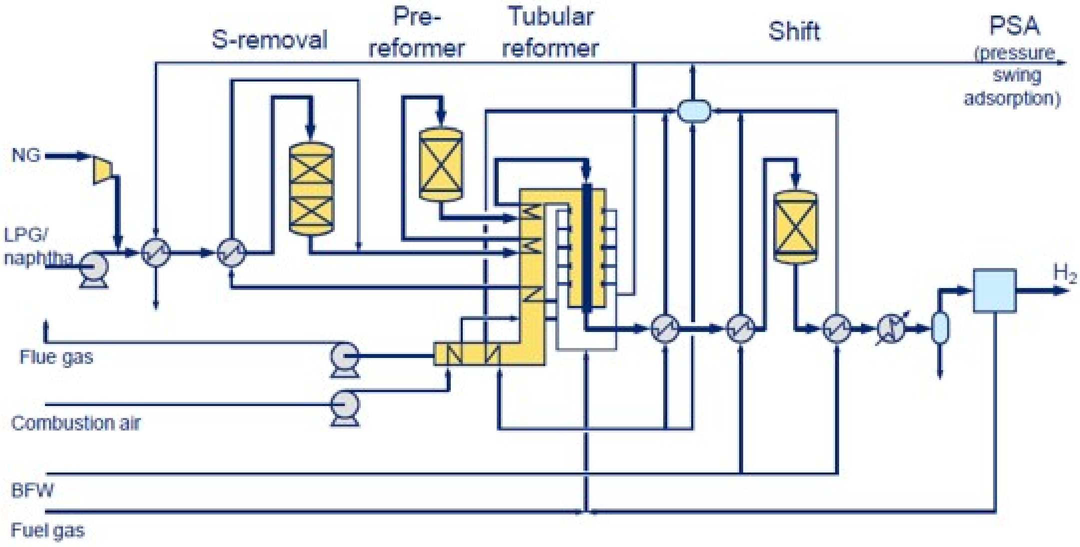


Figure 3 – Hydrogen Generation Process by Haldor Topsoe Company (PEIRETTI, 2013)

$CH_4 + H_2O = CO + 3 H_2$
(Steam Reforming Reaction – Endothermic)

$CO + H_2O = CO_2 + H_2$
(Shift Reaction – Exothermic)

The process is called autothermal because involves endothermic and exothermic reactions and, in theory, the heat produced in the partial oxidation reaction is consumed in the reforming reaction.

Autothermal reforming can produce syngas with H_2/CO ratio close to 2, adjusting the reactants proportion in the process feed. Normally the catalyst used in the process is nickel-based catalyst over alumina, however, coke deposition over the catalyst represents a challenge that needs to be overcome in the methane autothermal reforming too.

Like aforementioned, several technologies have been studied and developed, but at the moment methane steam reforming process still is the most economical route to produce hydrogen in large scale.

RENEWABLE HYDROGEN GENERATION ROUTES – FUNDAMENTAL ENABLER TO THE ENERGY TRANSITION

In the current scenario, is increasingly high the pressure from the society to energy transition efforts aiming to reduce the fossil fuels participation in the global energetic matrix. As aforementioned, the hydroprocessing technologies achieve a fundamental role in any refining hardware, but this fact has a side effect due to the high CO2 emissions during the natural gas steam reforming process to produce hydrogen.

Some refiners are adopting the co-processing of renewable materials in the crude oil refineries aiming to produce high quality and cleaner transportation fuels. Despite the advantages of environmental footprint reduction of the refining industry operations, renewables processing presents some technological challenges to refiners.

The renewable streams have a great number of unsaturations and oxygen in his molecules which lead to high heat release rates and high hydrogen consumption, this fact leads to the necessity of higher capacity of heat removal from hydrotreating reactors aiming to avoid damage to the catalysts. The main chemical reactions associated with the renewable streams hydrotreating process can be represented as below:

$R\text{-}CH{=}CH_2 + H_2 \rightarrow R\text{-}CH_2\text{-}CH_3$
(Olefins Saturation)

$R\text{-}OH + H_2 \rightarrow R\text{-}H + H_2O$
(Hydrodeoxigenation)

Where R represents a hydrocarbon.

These characteristics lead to the necessity of higher hydrogen production capacity by the refiners as well as quenching systems of hydrotreating reactors more robust or, in some cases, the reduction of processing capacity to absorb the renewable streams. In this point it's important to consider a viability analysis related to the use of renewables in the crude oil refineries once the higher necessity of hydrogen generation implies in higher CO2 emissions through the natural gas reforming process that is the most applied process to produce hydrogen in commercial scale.

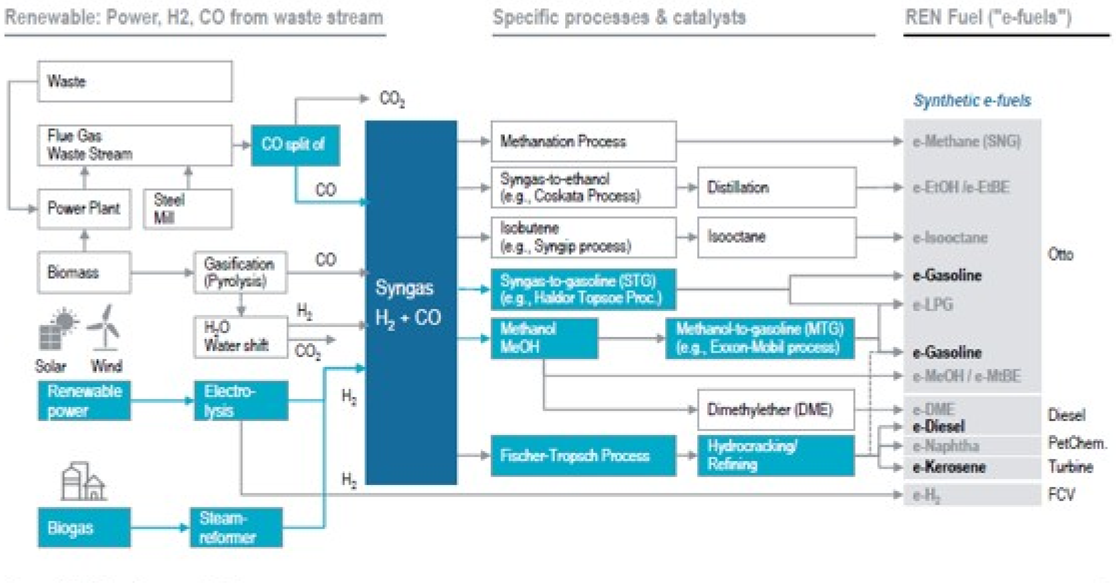
$CH_4 + H_2O = CO + 3H_2$
(Steam Reforming Reaction - Endothermic)

$CO + H_2O = \mathbf{CO_2} + H_2$
(Shift Reaction - Exothermic)

This fact leads some technology licensors to dedicate his efforts to look for alternative routes for hydrogen production in large scale in a more sustainable manner. Some alternatives pointed can offer promising advantages:

- Natural Gas Steam Reforming with Carbon Capture – The carbon capture technology and cost can be limiting factor among refiners;
- Natural Gas Steam Reforming applying biogas – The main difficult in this alternative is a reliable source of biogas as well as their cost.;
- Reverse water gas shift reaction (CO2 = H2 + CO) – One of the most attractive technologies, mainly to produce renewable syngas;
- Electrolysis – The technology is one of the more promising to the near future.

Figure 4 presents a processing scheme to produce hydrocarbons applying renewable hydrogen, based in the Roland Berger Company concept.



Source: Roland Berger, Company publications

Figure 4 – Hydrocarbons Production Routes Applying Renewable Hydrogen (Roland Berger Company, 2020).

As aforementioned, hydrogen is a key enabler to the future of the downstream industry and the development of renewable sources of hydrogen is fundamental to the success of the efforts to the energy transition to a lower carbon profile.

Recently, the literature is classifying the hydrogen production routes in four classes as follow (Based on IEA data from 2019):

1 – Brown Route – Hydrogen production from coal gasification without carbon abatement system (CCS). This route presents the higher emission rate of greenhouse gases (19 t CO2/ t H2) and an average production cost of US$ 1,2 to 2,1 per kg H2;

2 – Gray Route – This is the conventional hydrogen production route adopted by the most part of the refiners, which applies steam reforming of natural gas without CCS. This route still presents high emission of greenhouse gases (11 t CO2/t H2) and an average production cost of US$ 1,0 to 2,1 per kg H2;

3 – Blue Route – This route encompasses the conventional steam reforming of natural gas with CO2 abatement system. In this case, the CO2 emissions are drastically reduced (0,2 t CO2/ t H2), but the average production cost reaches US$ 1,5 to 2,9 per kg H2;

4 – Green Route – As presented above, the green route is based on electrolysis through renewable electricity. In this case it’s possible to reach zero CO2 emissions, but the average production cost is still considered high (US$ 3,0 to 7,5 per kg H2).

The technology development and scale-up gains tends to reduce the production costs of cleaner routes over the next years. Currently, the best alternative to refiners is to optimize the hydrogen consumption to keep under control the operating costs as well as, control the emissions of greenhouse gases.

Nowadays, as presented in Figure 5, the crude oil refining industry is the main hydrogen consumer followed by the ammonia production.

Still based on data from Figure 6, 71 % of the hydrogen produced by dedicated processes is from natural gas steam reforming and 27 % from coal gasification, both routes present high emissions of greenhouse gases (mainly CO2). According to the reference, the difference (close to 75 Mt of hydrogen) is related to the generation where the hydrogen is produced as a by-product like naphtha catalytic reforming or propane steam cracking as example. Crossing the data from Figure 6, it’s clear the relevance of the necessity of the energy transition efforts in the downstream sector to the success of the global transition to a low carbon and hydrogen economy.

THE GAS TO LIQUIDS TECHNOLOGIES – SYNGAS PRODUCTION

One of the most promising and well-developed technologies to produce liquid hydrocarbons from natural gas currently is the

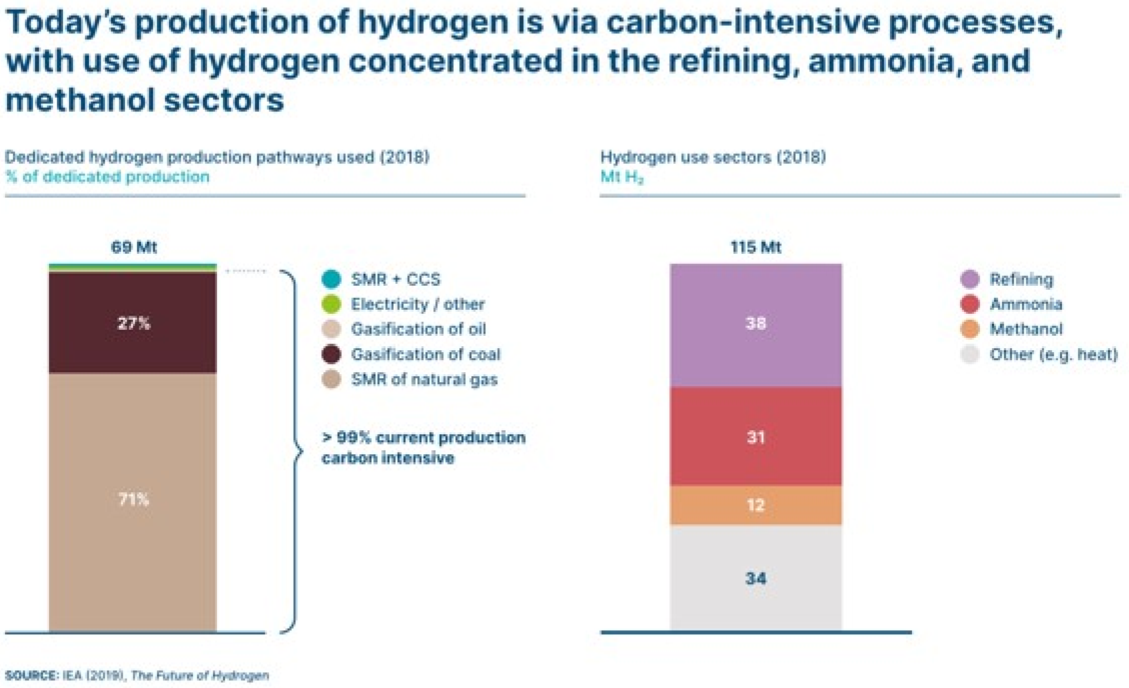


Figure 5 – Main Production Routes and Hydrogen Consumers (ETC Global Hydrogen Report, 2021)

conversion of syngas (CO + H2) in longer-chain hydrocarbons such as gasoline and other liquid fuel products, known as Gas to Liquids Technologies (GTL). The liquid hydrocarbons production can be carried out by direct syngas conversion, in Fischer-Tropsch synthesis reactions or through methanol production as intermediate product (Methanol to Olefins technologies).

Showed process in Figure 6 is based in the syngas gas generation from steam reforming of natural gas, this is the most common route, however, there are process variations applying syngas production through coal, biomass, or petroleum coke gasification route.

The process starts with syngas generation and, as aforementioned, the produced hydrocarbon chain extension is controlled in the Fischer-Tropsch synthesis step through the CO/H2 ratio in the syngas fed to the FT reactors (beyond temperature and reaction pressure), following the produced hydrocarbons are separated and sent to refining steps as isomerization, hydrotreating, hydrocracking, catalytic reforming, etc. According to application of the produced derivative (Gasoline, Diesel, Lubricant, etc.).

Some side reactions can occur during the hydrocarbons production process, leading to coke deposition on the catalyst, causing

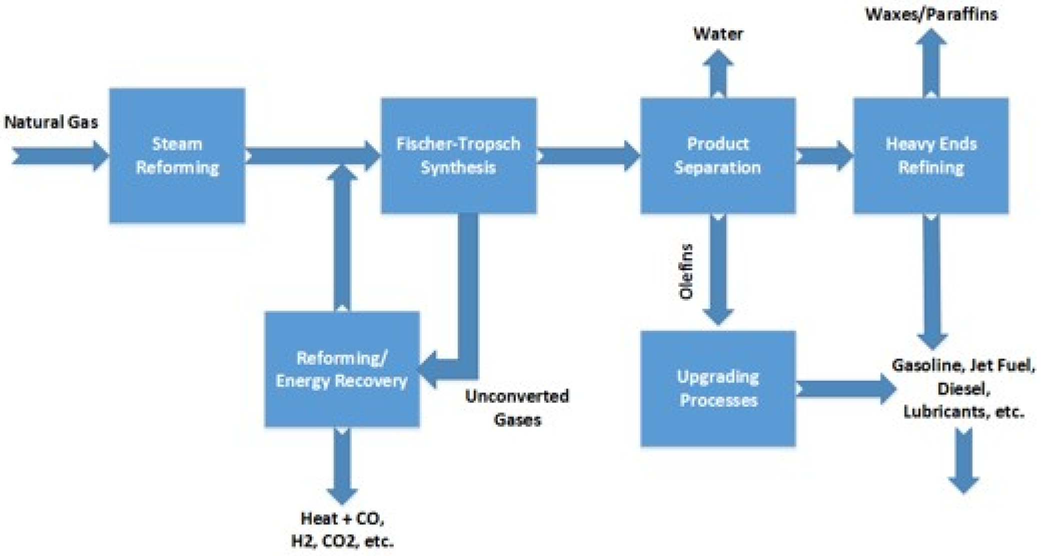


Figure 6 – Block Diagram to a Typical Fischer-Tropsch GTL Process Plant.

his deactivation according to following chemical reactions:

$2\ CO = C + CO_2$
(Boudouard Reaction)

$CO + H_2 = C + H_2O$
(CO Reduction)

The type of reactor applied in the FT synthesis step have strong influence on the yield and quality of the obtained products, the campaign time of the process units also depends on the type of reactor. Fixed bed reactors are widely employed to FT synthesis, however, show a reduced campaign time due to the low resistance to catalyst deactivation phenomenon. Modern process units apply fluidized bed or slurry phase reactors that present a higher resistance to coke deposition on the catalyst and better heat distribution, leading to higher campaign periods.

Most recently is observed a reduction trend in the demand by transportation fuels and some refiners are looking for change his production focus from transportation fuels to petrochemicals. The gas to liquids can be applied in synergy with conventional refining processes to improve the yield of petrochemicals in the refining hardware through the production of high quality naphtha that can be applied to FCC or steam cracking units to produce light olefins, ensuring higher added value to the processed crudes and gas as well as participation in a growing market.

Another attractive alternative and synergy opportunities to refiners is the production of ammonia that are the base of any fertilizer.

Despite the flat demand over the last years, is expected a growing market in the next years due to the increasingly demand by food at global level. As presented in Figure 7, is also expected a growing demand of Methanol in the next years, this intermediate can be used to produce high demand products like formaldehyde that is applied to produce plastics and coatings, allowing great added value to the crude oil and natural producing chain.

METHANOL TO OLEFINS/GASOLINE TECHNOLOGIES – LIQUID HYDROCARBONS FROM METHANOL

Another alternative route to produce liquid hydrocarbons from syngas is the non-catalytic conversion of the natural gas to methanol followed by the polymerization to produce alkenes. Methanol is produced from natural gas according to the following chemical reactions:

$CH_4 + H_2O = CO + 3H_2$
(Steam Reforming)

$CO + H_2O = CO_2 + H_2$
(Shift reaction)

$2H_2 + CO = CH_3OH$
(Methanol Synthesis)

In the sequence, the methanol is dehydrated to produce Dimethyl-Ether which is posteriorly dehydrated to produce hydrocarbons, as shown in the sequence:

$2\ CH_3OH = CH_3OCH_3 + H_2O$
(Methanol Dehydration)

$CH_3OCH_3 = C_2H_4 + H_2O$
(Dimethyl-Ether Dehydration)

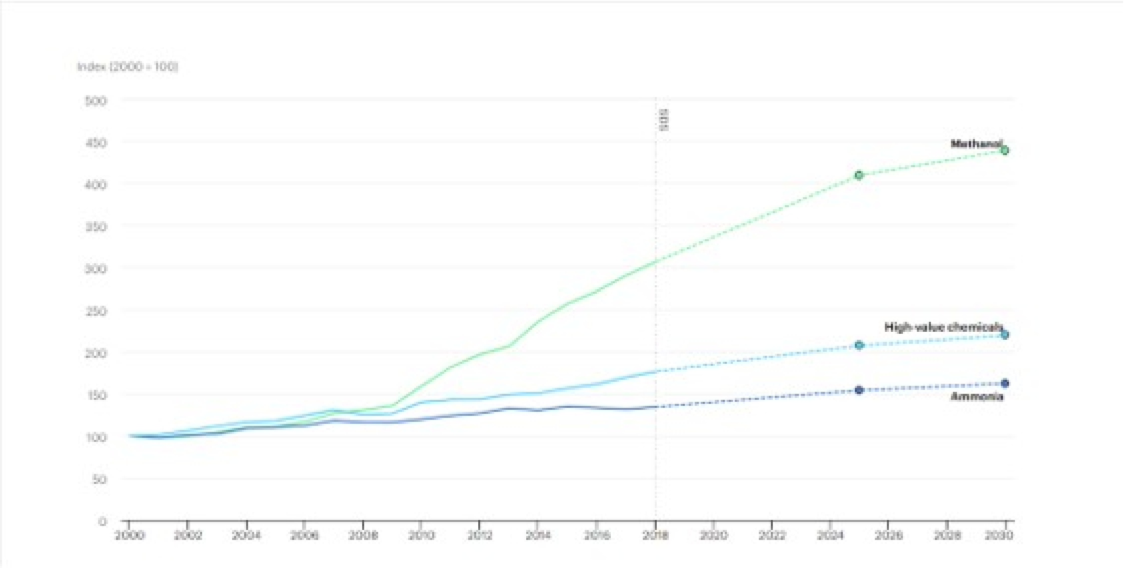


Figure 7 – Primary Chemicals Production Forecast (IEA, 2020)

The methanol conversion to olefins into hydrocarbons is called Methanol to Olefins (MTO) or Methanol to Gasoline (MTG) technologies. Figure 8 presents a typical unit dedicated to produce methanol from natural gas through the two-step reforming process.

An alternative technology developed by the Haldor Topsoe Company to produce methanol from natural gas is the Altothermal reforming process, called ATR™ that offers improvements related to the reforming furnace. A significant advantage of the ATR™ process is the lower required ration Steam/Carbon in the reforming step that offer great scale economy when compared with traditional production processes (One step and two-step reforming processes). Figure 9 presents a basic process flow diagram for the ATR™ process, developed by Haldor Topsoe Company.

The most known processes dedicated to converting methanol in hydrocarbons are the processes MTG™ developed by ExxonMobil Company and the MTO-Hydro™ process, developed by UOP Company. Figure 10 presents the process flow diagram for the MTG™ process by ExxonMobil Company.

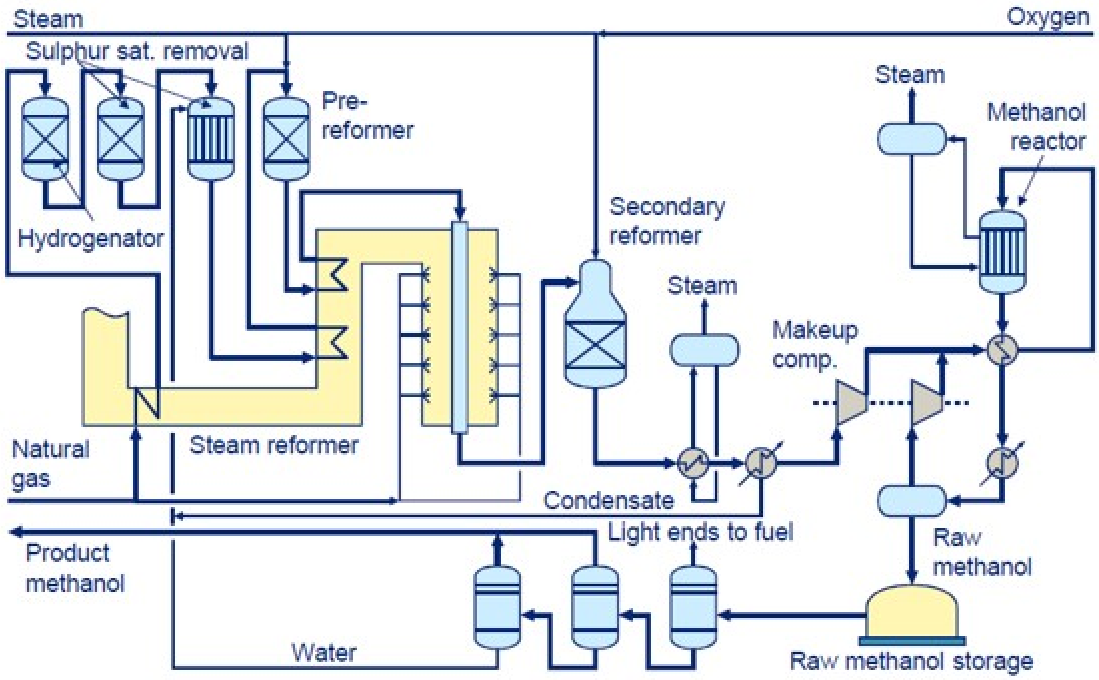


Figure 8 – Methanol Production Process from Natural Gas through two-reforming Process (PEIRETTI, 2013)

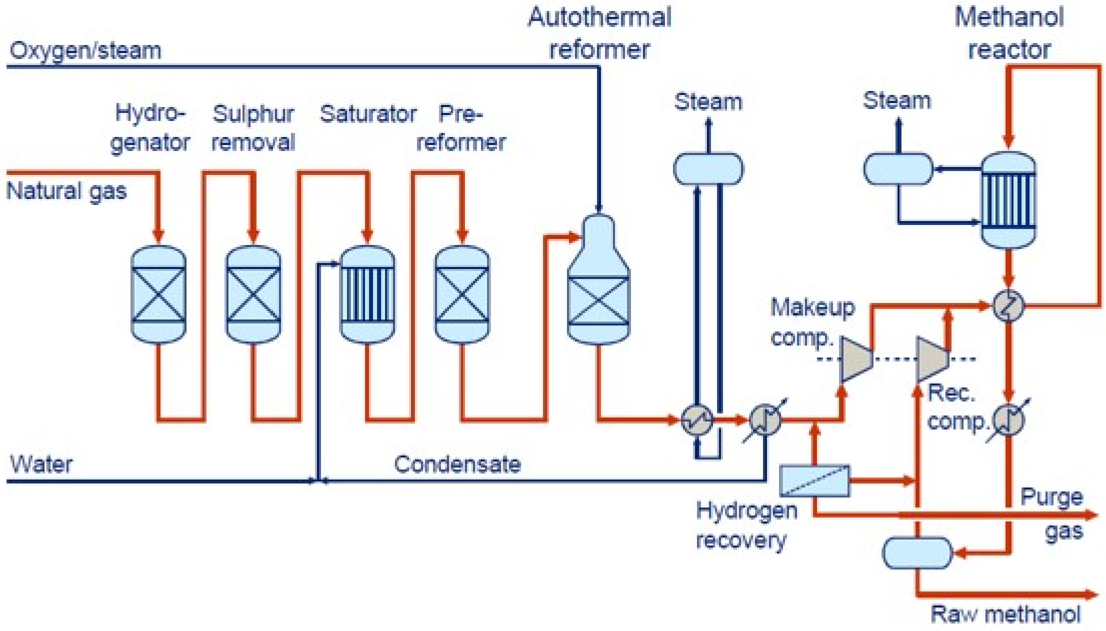


Figure 9 – Altothermal (ATR™) Process for Methanol Production from Natural Gas by Haldor Topsoe Company (PEIRETTI, 2013)

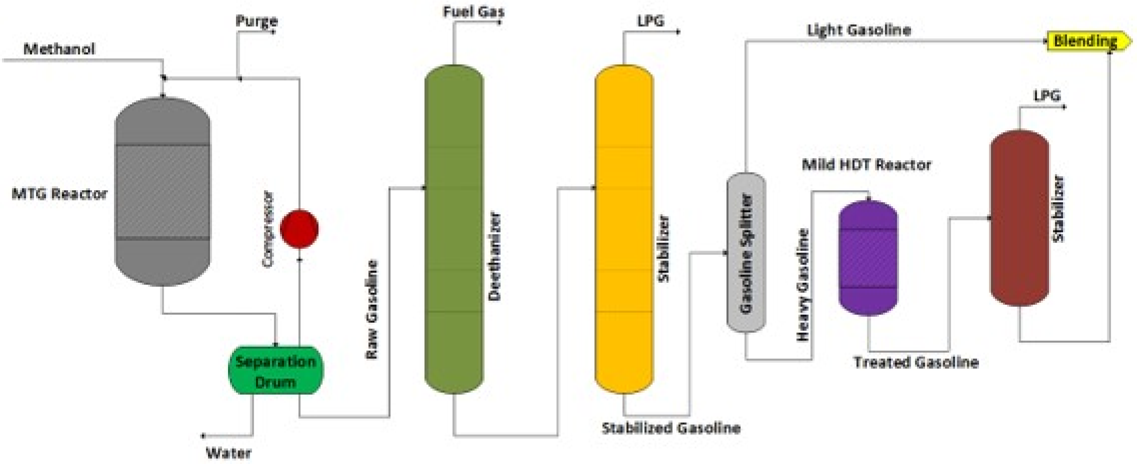


Figure 10 – Process Flow Diagram for MTG™ Technology by ExxonMobil

The MTO technologies presents some advantages in relation to Fischer-Tropsch processes, once show higher selectivity in the hydrocarbon production, furthermore, the obtained products require lower additional processing steps to achieve commercial specifications, another important point in that the installation cost is normally lower to MTO process plants when compared with FT units, once Fischer-Tropsch units are economically viable only in large scale. Regarding the olefins production, the maximization of these derivatives can be especially attractive in the current scenario where there is a trend of reduction in transportation fuels demand followed by the growing market of petrochemicals, creating the necessity of closer integration between refining and petrochemical assets aiming to maximize the added value, share risks and costs, as well as ensure market share in a highly competitive scenario of the downstream sector. Other great technology developers for methanol production process are Johnson Matthey Company, Linde Company, Chiyoda Corporation, and Jacobs Company.

HYDROGEN NETWORK AND MANAGEMENT ACTIONS IN CRUDE OIL REFINERIES

As mentioned above, the hydrogen became a fundamental production input to modern crude oil refineries and his adequate management is a key factor to ensure controlled operating costs and competitiveness in the market, as well as allow the production of marketable crude oil derivatives. The hydrogen management actions start with a mass balance involving the hydrogen network that is composed by hydrogen sources, hydrogen purification systems, and the hydrogen consumers as presented in Figure 11.

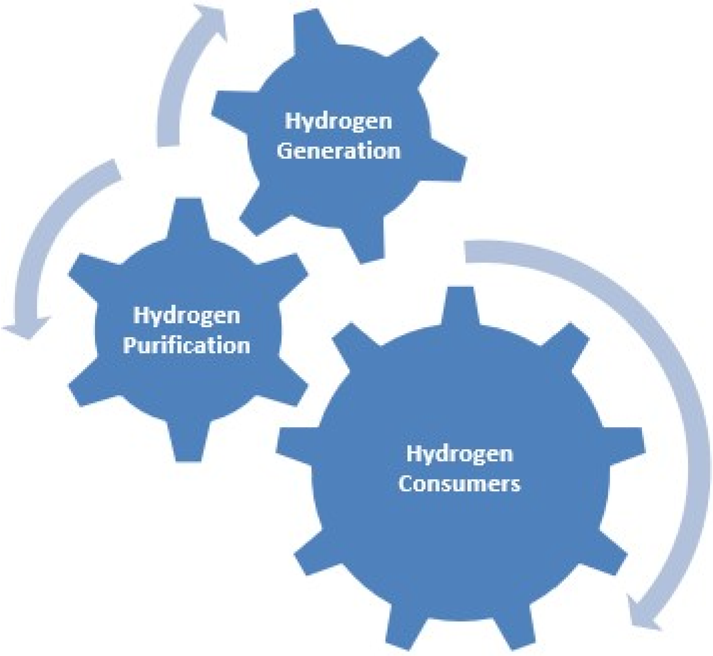


Figure 11 – A Typical Hydrogen Network in a Crude Oil Refinery

The hydrogen generation relies on the refining configuration adopted in the refinery. Normally, refineries that rely on Catalytic Reforming units apply the hydrogen produced in this process unit to compose a relevant part of the hydrogen network becoming an important internal source of hydrogen. As presented above the hydrogen generation route most applied in the refining industry is the steam reforming based on naphtha or natural gas like described by Figure 2.

The hydrogen purifying technologies is another important part of hydrogen network, normally the modern refineries apply Pressure Swing Adsorption (PSA) technologies to purify the hydrogen, reaching purity higher than 99 %. Despite this fact some refiners still use treatments based on amine treatment, as depicted in Figure 12.

Despite the lower capital cost requirement when compared with PSA technologies, the amine treating units produce hydrogen with low purity and this represent great disadvantage, especially to refiners with deep conversion hydroprocessing units. Another hydrogen purifying technologies commercially available are the membrane separations that can reach purity of 98 % and the cryogenic processes that can reach 96 % of purity. The hydrogen purifiers have a key role in the hydrogen management once control the hydrogen recovery in off-gases, one of the main sources of hydrogen losses in the refineries is the burn as fuel gas during poor recovery capacity.

The hydrogen consumers in a crude oil refinery are composed by hydroprocessing units that can be hydrotreating and hydrocracking units, as presented in Figure 13.

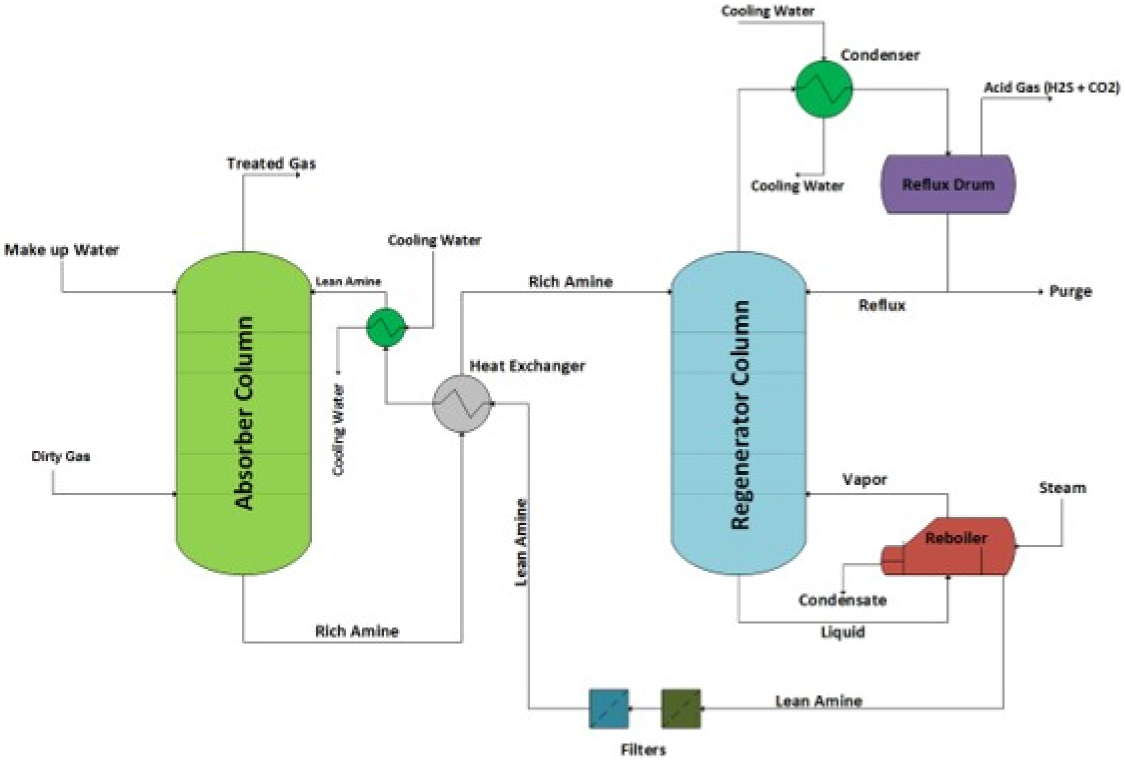


Figure 12 – Typical Amine Treating Unit

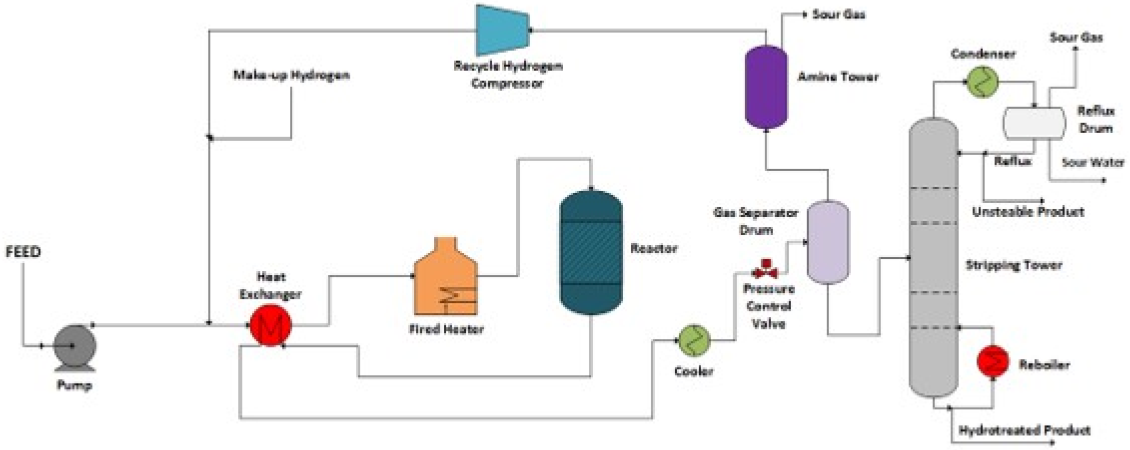


Figure 13 – Typical Low Severity Hydrotreating Unit

According to the refining configuration, the hydrogen consumers in a crude oil refinery can vary, an example is the refineries that rely on isomerization units to increase the production of high-quality gasoline.

The high cost of hydrogen generation as well as the great amount of CO2 (Greenhouse gas) produced is the main driving force to an adequate hydrogen management in the refining hardware. Process integration technologies like pinch method and mathematical modeling are being applied to reach a most rational use of hydrogen in the refining hardware.

The reliability of hydrogen purification systems as well as the optimization of hydroprocessing units is fundamental to avoid the burn of hydrogen in the fuel gas ring or flare that can raise the operating costs and reduce the refining margins of the refiners. Another key point is the availability of control and instrumentation systems to allow the flow measurement and adequate accuracy of mass balances and actions to define optimization actions and mathematical modeling.

CONCLUSION

The hydroprocessing technologies became fundamental to the downstream industry both to produce high quality and cleaner derivatives or to prepare feedstocks to the processing units like residue fluid catalytic cracking and this dependence raised, even more after the start of IMO 2020 that requires a deep treatment of bottom barrel streams aiming to comply with the new quality requirements of the marine fuel oil (Bunker). In this sense, the hydrogen generation units achieve strategic character to refiners and the efficient and reliable operation of these units needs to be a priority to refiners.

Nowadays, the cleaner routes of hydrogen production still present higher costs of the traditional routes, but the pressure from the society tends to create stricter regulations forcing the refiners to adopt these routes, especially the blue route in short term, this scenario call the refiners to a more efficient and optimized use of hydrogen in the refining and petrochemical assets. Under this environment, the petrochemical integration necessity of the refining hardware tends to be reinforced once, normally, the petrochemical plants present a surplus of hydrogen which can be offered to integrated refiners with relatively low cost and without new contributions of CO2 emissions.

Beyond the current status, it’s important to understand that the energy transition is no longer a choice matter to the players of the downstream industry, but a reality, and the efforts to find cleaner sources of hydrogen needs to be supported to refiners aiming to minimize the environmental impact of crude oil processing chain at the same time to ensure the production of high quality and added value derivatives.

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Rock Bottom View:

Monday, December 5, 2022
Was an Important Day in Science

Fusion Nuclear Power Finally!....But Is It Safe?

Ronald J. Cormier, *Engineering Practice* Contributing Author

Happy 2023! As has been the case since EPM's September 2022 edition, I continue penning *TVRB* while on my travels in Mexico, where it's warm and mild: a truly always-comfortable climate. That said, I expect that I will return shortly after the holidays to author the March 2023 edition from the old ranch porch back in Central Texas, probably until the weather likely again proves unbearable this summer.

Most of us are involved with precision designs which combust, and/or chemically manipulate hydrocarbons, but also "along for the ride", we stoichiometrically produce CO2, NOx, ozone, etc. These are generally undesirable by-products. Generated throughout the twentieth century and through to present times, these gases have been determined to negatively affect the earth's protective atmosphere.

We generally understand and accept mandates toward achieving "zero emissions" from our processes during the 2030-2050 period, depending on various bureaucratic and cultural edicts. Most major firms, currently producing offending emissions to water, land, or air, are at least beginning paradigm steps to improve methods geared toward achieving a better environment for future generations on planet Earth. Wind and solar alternatives will help, though issues still impede these energy sources from easy substitutes for oil/gas. Additional innovation is required to produce seamless flow of energy or product via wind/solar.

Nuclear power has often been regarded as either a miracle or a pariah, depending on your individual viewpoint. Nuclear plants must be taken care of properly to avoid a meltdown. If from uranium fission, the radioactive waste that is produced must be stored carefully so that it does not come into contact with the outside environment. In fact, any material that becomes contaminated can remain radioactive for thousands of years! Most nuclear fuel is stored underwater, but a few reactors store the older and less radioactive fuel in storage facilities located outdoors, protecting the structures with special concrete or steel shielding. Since the late 1950's, this inevitability has drawn the ire of global environmentalists.

However, that all may be changing. Scientific breakthroughs are finally occurring. "Monday, December 5, 2022, was an important day in science," Jill Hruby, the National Nuclear Security Administration Administrator, said at a press conference announcing the news in Washington D.C. "Reaching ignition in a controlled fusion experiment is an achievement that has come after more than 60 years of global research, development, engineering and experimentation."

Reaching ignition means the fusion experiment produced more energy from fusion than the laser energy that used to drive the reaction. Since the experiment, the team has been analyzing data to be able to make this official announcement.

"This is important. Earlier results were records, but not yet producing more energy out than was put in," Andrew Holland, the CEO of the industry's trade group, the Fusion Industry Association told CNBC. "For the first time on Earth, scientists have confirmed a fusion energy experiment released more power than it takes to initiate, proving the physical basis for fusion energy. This will lead fusion to be a safe and sustainable energy source in the near future."

In the experiment on Dec. 5, about two megajoules (a unit of energy) went into the reaction and about three megajoules came out, said Marvin Adams, Deputy Administrator for

Defense Programs at the National Nuclear Security Administration. “A gain of 1.5,” Adams said.

For the experiment, super high-powered lasers are all directed at a very tiny fuel target at the National Ignition Facility at the Lawrence Livermore National Laboratory in California. “During experiments, 192 high energy lasers converge on a target about the size of a peppercorn heating a capsule of deuterium and tritium to over 3 million degrees Celsius and briefly simulating the same process that powers the sun and stars,” Hruby said. This could eventually lead to an unlimited source of cheap, clean energy since no CO2 or waste is produced.

The main mission of the National Lab is studying nuclear power for use in national defense. This nuclear fusion research is part of an effort established in 1996 by then President Clinton to maintain confidence in the safety of nuclear weapons stockpiles without full-scale nuclear testing. But this discovery has massive implications for clean energy, too. In addition to the national security work, “we have taken the first tentative steps towards a clean energy source that could revolutionize the world,” Hruby said.

While this scientific breakthrough is being celebrated at the highest levels of government, it will be many years before fusion power plants are likely to provide clean abundant energy. “This is one igniting capsule, one time. And to realize commercial fusion energy, you have to do many things. You have to be able to produce many, many fusion ignition events per minute,” Kim Budil, the director of the Lawrence Livermore Lab, said on Tuesday.

“You have to have a robust system of drivers to enable that. So, you know, probably decades. Not six decades, I don’t think. Not five decades, which is what we used to say. I think it’s moving into the foreground and probably, with concerted effort and investment, a few decades of research on the underlying technologies could put us in a position to build a power plant.”

Omar A. Hurricane, Chief Scientist for the Inertial Confinement Fusion Program at Lawrence Livermore, explained, “What remains to be done from here is largely engineering, of increasing the laser energy efficiency and increasing the target energy gain with further target optimizations.”

Hurricane added, “This new result does indeed bring commercial fusion closer, as it demonstrates that there are no fundamental physics obstacles. It is starting to feel like we are entering the ‘Fusion Age.’” Interest in fusion has increased dramatically in recent years as concerns about climate change and energy security have become more acute.

More than 90 nuclear fission reactors currently operate in the United States, which employ a neutron smashing into a larger atom, causing it to split into two smaller atoms and releasing a lot of energy. Nuclear fission reactions do not release any carbon dioxide emissions and therefore are considered clean energy, according to the US Department of Energy.

The United States got approximately 19% of its utility-sized electricity generation from those nuclear power fission plants in 2021, according to the U.S. Energy Information Administration. The energy from nuclear fission reactors represents half of the clean power generated in the United States. However, those reactors generate long-lasting nuclear radioactive waste, and most countries, including the United States, currently have no long-term storage facilities for that waste. Efforts to build a permanent, underground geologic storage facility for nuclear waste have so far, not gained support.

While the fusion reaction avoids waste and associated storage, it’s proven extremely challenging to sustain a fusion reaction here on earth, and scientists have been trying for decades. In particular, it requires massive amounts of energy to generate fusion on reactions, and until this experiment, nobody had demonstrated the ability to get more energy out of the reaction than it takes to power it. “Scientists have struggled to show that fusion can release more energy out than is put in since the 1950s,” plasma physicist Arthur Turrell told CNBC. The researchers at Lawrence Livermore have done this for the first time ever.

Fusion is already a hot space for climate and energy investors. Investors have poured almost $5B into private fusion energy startups, according to the Fusion Industry Association, and more than half of that has been since the second quarter of 2021.

Indeed, the private fusion industry is seeing this as a win. In short, this will show the world that fusion is not science fiction: it will soon be a viable source of energy. Of course, there are still many steps between these experimental results and commercial fusion power plants, providing our upcoming STEM graduates with a rich and concentrated career paths (think IACPE Certification too!!!). Bottom Line: the Livermore breakthrough is an important milestone that brings us closer to the day when nuclear fusion will provide the world with clean, safe, and abundant energy.

In closing (and to especially to our readers in Europe, already starting to experience a shortage of winter heating products, due to the Russian/Ukrainian war), I can only imagine the avoided human pain and hardship, if nuclear fusion technology was at a commercial stage today.

Until the EPM March 2023 edition, I bid you a safe and prosperous winter.

Potential of Renewable Green Hydrogen Production in Shores of Countries (Offshore & Onshore)

Hamid Reza Seyed Jafari, Dr. Ahmad Shariati, Seyed Mohammad Reza Seyed Jafari

Global warming is the result of increase in fossil and non-renewable fuel consumptions.
Several oil & gas countries have started renewable energy and green gas production programs.

Almost all seashore countries have the potential to be a sector in renewable energy and green hydrogen gas production.

ABSTRACT

The phenomena of industrialization and transportation greenhouse gases production lead to increase in global warming. The currently increase in the global warming caused global environmental protection experts and decision-makers in the United Nations Organization to encourage countries to define and execute their action plans to reduce the global warming. The action plans comprise of decreasing the consumption of fossil fuels and/or to substitute them with renewable energies and gases. The ultimate goal is to reach net zero emission GHG's and prevent climate change environmental impacts in the worldwide in the third millennium AD.

KEY WORDS

Global warming, Green hydrogen gas, Climate change environmental impacts, Net zero emission GHG's, Renewable energy, Technology .Technology transfer, Decarbonization, PTX (P2X) ,Offshore & Onshore , Energy transition

INTRODUCTION

As usual, oil & gas producing, and industrial countries are among the top ten greenhouse gas producing countries in the world due to its huge oil and gas reserves or its consumption.
Therefore, these countries, in addition to having huge resources and consumption of petroleum and fossil gas, have potential to spread warming global and climate change impact then should invest and implement technological substitution plans to become a regional hub in renewable energies and green gases production in the worldwide. Of course, there may be few challenges in this approach energy transition in this new field of energy.

Currently, most of the countries that have: A) huge oil and gas hydrocarbon resources B) offshore and onshore areas C) natural sources of renewable energies such as solar and wind, have started long-term plans for large-scale decarbonization P2X projects in the form of green hydrogen gas production by electrolysis technology with the perspective of the years 2030, 2040 and 2050.

HYDROGEN GAS

Hydrogen gas (H_2) can be considered as a completely clean gaseous fuel after natural gas (CH_4) with a suitable heating value. Based on the type of feedstock, there are few types of hydrogen gas as follows:

- Blue hydrogen (based on fossil methane feed)
- Brown hydrogen (based on coal methane feed)
- Green hydrogen (based on bio methane or electrolyzed water feed).

HYDROGEN PROCESS PRODUCTION & HEATING VALUE

Hydrogen gas is produced in various ways in the industry. For example, in non-renewable energy industries, it is mainly obtained from reforming natural gas process (1), and in non-renewable energy industries, it is produced through the electrolysis process of water (2) in offshore & onshore of the seas and oceans:

- steam methane reforming (SMR) : $CH_4 + H_2O + Q = 3H_2$ (blue or gray)+ CO (1)
- Electrolysis of water : $2H_2O$ + DC electricity = $2H_2$ (green) + O_2 (2)

Gaseous Fuels @ 32 F and 1 atm	Btu/lb (HHV)
Natural gas (Methane)	22,453
Hydrogen	61,127
Liquefied petroleum gas (LPG)	21,561
Conventional gasoline	20,007
Low-sulfur diesel	19,594
Liquefied natural gas (LNG)	23,734

Table 1—Heating values of Hydrogen gas and fuels (https://chemeng.queensu.ca/courses/CHEE332/files/ethanol_heating-values.pdf, 2022)

On a BTU/lb basis, Hydrogen has about 2.5 times the energy density of methane. So, if you burn one pound of hydrogen vs one pound of natural gas (Methane), you will get 2.5 times the energy (Table 1).

WATER ELECTROLYSIS TO PRODUCE GREEN HYDROGEN GAS

Today, one of the most important global decarbonization projects to deal with climate change is the water electrolysis project with the help of renewable electricity (such as: wind/solar/...) in the vicinity of sea water to produce green hydrogen fuel and renewable energy (Figure 1).

- Water Electrolysis : $2H_2O$ + Renewable electricity = $2H_2$ (green) + O_2

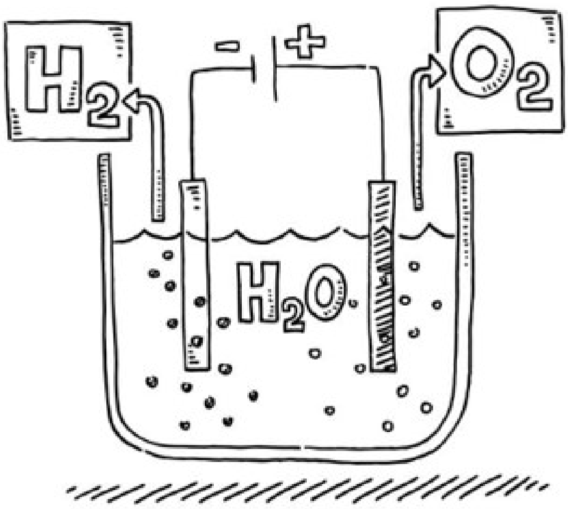


Figure 1 – Water electrolysis

DIRECT CURRENT ELECTRICITY NEEDED TO WATER ELECTROLYSIS

The water electrolysis process requires direct current (DC) electricity. Therefore, wind/solar/...renewable electricity generation sources are considered the best electricity supply options for the water electrolysis process. Of course, if alternative current (AC) is also available, it can be converted to direct current with an inverter. Therefore, if there are huge water resources (such as seas) in the vicinity of solar or wind renewable electric energy production sources on the coasts of the sea or in the seas, the technological process will be easily applicable (Figure 2).

Figure 2 – Supply chain of green hydrogen production from water electrolysis by renewable electricity (Ref.:Azocleantech.com, 2022)

Of course, in this regard, the appropriate placement of these God-given renewable resources in terms of sun intensity/wind speed and proximity to the possible pipeline transmission lines (to transfer hydrogen gas to the source of consumption) can all be considered as part of the main parameters of the challenges and opportunities of conducting electrolysis technology in the offshore or onshore, which requires detailed engineering studies.

GREEN HYDROGEN PRODUCTION : CURRENT STATE AND OUTLOOK IN COUNTRIES

This section of the article compares the current and future situation of green hydrogen production by electrolysis technology in the offshore and onshore sectors in different countries (Figure 4).

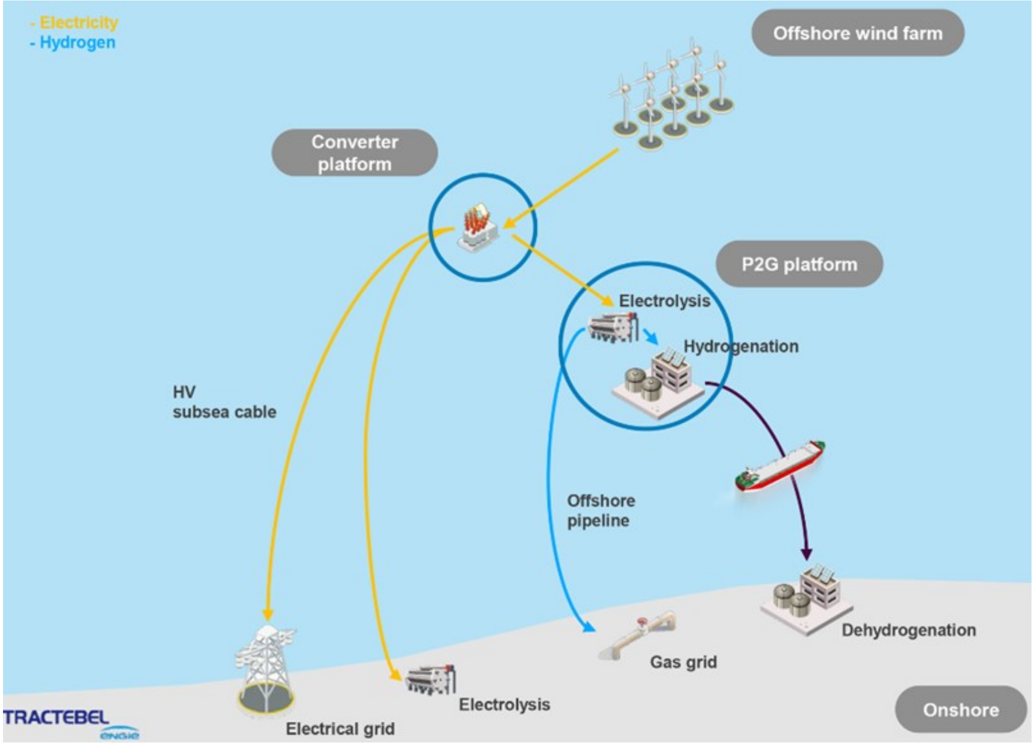


Figure 4.Supply chain of green hydrogen and renewable electricity in offshore & onshore (Reference: https://tractebel-engie.com/en , 2022)

OMAN

Oman is planning to build one of the largest green hydrogen plants in the world in a move to make the oil-producing nation a leader in renewable energy technology.Construction is scheduled to start in 2028 in Al Wusta governorate on the Arabian Sea. It will be built in stages, with the aim to be at full capacity by 2038, powered by 25 gigawatts of wind and solar energy.The consortium of companies behind the $30bn (£21bn) project includes the state-owned oil and gas company OQ, the Hong Kong-based renewable hydrogen developer InterContinental Energy and the Kuwait-based energy investor Enertech.Once online, the plant will use renewable energy to split water in an electrolyser to produce green hydrogen, which is able to replace fossil fuels without producing carbon emissions. Most will be exported to Europe and Asia, said Alicia Eastman, the co-founder and president of InterContinental Energy, either as hydrogen or converted into green ammonia, which is easier to ship and store. The facility aims to produce 1.8m tonnes of green hydrogen and up to 10m tonnes of green ammonia a year.

Oman currently relies heavily on fossil fuels, generating up to 85% of its GDP from oil and gas, but its fossil fuel reserves are dwindling and becoming increasingly costly to extract. In December 2020, the country published its Oman Vision 2040 strategy, a plan to diversify the economy away from fossil fuels and increase investment in renewables.Green hydrogen could play an important role, said Eastman, thanks to the Oman's combination of plentiful daytime sun and strong winds at night. "Oman is one of the places in the world that I've called the 'future renewable superpowers'," said Michael Liebreich, the founder of BloombergNEF, "because what you really want [to produce green hydrogen] is very cheap solar and very cheap wind."While electrification is the most efficient way of decarbonising most sectors, it's limited when it comes to energy-intensive industries such as steel, chemicals, aviation and shipping. Green hydrogen will be vital to help fill these gaps, said the International Energy Agency in its report published this week, which called for an end to fossil fuel investments if governments are serious about climate commitments.A wave of net zero-emissions pledges has already led to a slew of hydrogen strategies, including from the European Commission in 2020, which predicted the share of hydrogen in the EU's energy mix would rise from 2% to 14% by 2050.(1)

CHINA

China's Sinopec International Petroleum Service Corporation is building the world's biggest plant for the production of hydrogen from renewables The factory will be powered by a 300 MW #photovoltaic plant is expected to be put into operation 2023 Sinopec plans to produce 20,000 tons of green hydrogen a year once the facility is completed while the expected reduction of #co2emissions about 485,000 tons a year The plant located in the northwestern region of #xinjiang will cost about USD 470.8 million to build with #solarpanels covering an area of over 630 hectares. The cost of hydrogen production there will be only USD 2.67 /kg according to media SINOPEC announced that the project would cover the whole process of #greenhydrogen production and utilization from solar power generation electrolytic production storage and transportation It will include 300 MW solar power plant a #waterelectrolysis hydrogen production plant hydrogen storage tanks, and a hydrogen pipeline #greenhydrogen will replace natural gas based hydrogen used at Sinopec's #Taheoilrefinery Sinopec estimates that in the future the whole #petroleumindustry will create a market worth more than USD 14.8 billion by replacing #greyhydrogen which is produced using #electricity generated from #fossilfuels #cop27 #cop26.(2)

BRAZIL

Brazilian chemical maker Unigel on Monday announced plans to build a green hydrogen plant in the northeastern state of Bahia, with an initial investment of $120 million and the goal of making it one of the largest of its kind in the world.The plant is expected to start operations by the end of 2023, Unigel said in a statement. The first phase of the project foresees a production capacity of 10,000 tonnes of green hydrogen and 60,000 tonnes of green ammonia per year.

The electrolysis process for hydrogen production at the Bahia plant will be carried out in equipment supplied by Germany's ThyssenKrupp Nucera, controlled by Thyssenkrupp AG (TKAG.DE), totaling 60 megawatts.

- Green hydrogen and ammonia produced in the industrial city of Camacari will be offered to customers looking to decarbonize their operations, Unigel said.

Earlier this year, Fortescue Future Industries signed a pre-contract to develop a plant in Pecem while Shell (SHEL.L) announced a project in Rio de Janeiro's Acu port. Unigel said that in a second phase of its Camacari project, seen happening in 2025, it expects to quadruple the output of green hydrogen and ammonia. (3)

UAE

Abu Dhabi ports is planning 2GW green hydrogen to ammonia project. (4)

IRELAND

Floating wind and hydrogen | Project Dylan, a world leader. In the aftermath of two strategic sessions Holistic Network Design and Floating wind for the Celtic Sea, the community may welcome and update on Floating Wind and Hydrogen a devolved government commitment to net zero and Wales Hydrogen Pathway. (5)

SOUTH KOREA

Corio and TotalEnergies' floating wind farm, called Ulsan Gray Whale 3, is planned to be built around 60 to 70 kilometres from Onsan Port in Ulsan. #floatingwind #hydrogen #cluster #apac #ulsan #hyundai #hydrogeneconomy #shipping #vessels .#netzero Join the experts group: https://bit.ly/3hbRE4A Corio, TotalEnergies Award FEED Contract for 504 MW Floating Wind Farm in South. (6)

SAUDI ARABIA

The plant is being built by Pennsylvanian company Air Products, which agreed a deal for the scheme in July 2020. This envisaged a system that will use some 4GW of wind and solar electricity to produce more than 650 tonnes of hydrogen a day from 120 Thyssenkrupp electrolysers, each about 40m long.The hydrogen will be made in the form of ammonia, which is easier to transport than hydrogen in its liquid form.So far, site preparation work has been in progress, and this will give way to building in the next few days.

The announcement was made by Peter Terium, the chief executive of Enowa, which is Neom's energy, water and hydrogen subsidiary. He told the Bloomberg news agency that the plant would enable Saudi Arabia to compete with China, South Korea, Europe and the US, all of which are ramping up their own hydrogen sectors.Alongside the green hydrogen market, state oil producer Saudi Aramco is developing blue hydrogen production, with the help of Air Products and Saudi utility ACWA Power International. Blue hydrogen is made from natural gas.The Neom economic zone is located in Saudi Arabia's northwest, on the coasts of the Red Sea and Gulf of Aqaba. As well as advanced manufacturing, it will be home to The Line, a car-free, zero-carbon city with 1 million inhabitants and no roads, laid out as a 170km-long belt with services and transport infrastructure built underground. (7)

SCOTLAND

Developers can apply for the rights to build small-scale innovative offshore wind projects, of less than 100MW, and projects which will provide green electricity to oil and gas infrastructure to reduce their carbon emissions. Crown Estate Scotland's final leasing documents have been optimised to support early project development and reflect many of the comments and suggestions from potential applicants, who were asked for feedback earlier this year. These include extending Option Periods from five to seven years and doubling Lease Periods from 25 to 50 years for electrification projects.(8)

GERMANY

HH2E and MET Group are building one of the largest plan €1bn German green hydrogen project #greenhydrogen production facilities in #europe It will operate with an input power of 100 MW (6,000 tons/y of H2) by 2025 and 1 GW (60,000 tons/y of H2) by 2030. #greenhydrogen is essential for our energy transition, security of supply and energy sovereignty. (9)

NAMIBIA

Hydrogen megaproject Progress on $10bn Namibian green hydrogen project.The project will produce approximately 350,000 tonnes of green hydrogen per year, with 5-6GW of renewable generation capacity paired with 3GW of electrolysis capacity. (10)

THE NETHERLANDS

The technology can be used to transport hydrogen, CO2, ammonia and water, where steel solutions suffer from embrittlement and corrosion. As TCP is a flexible pipe, it can be installed offshore easily and quickly, using the same methods as currently used for array cables, #Netherlands has announced new plans to develop a national transport network for #hydrogen The network will connect #ports large industrial clusters in the country and storage locations for hydrogen. Connections with #Germany #Belgium will also be established. The network will be developed and operated by Gasunie Dutch Minister for Climate and Energy Rob Jetten also said he would look into whether the company can fulfil the role of #offshoregrid operator, given the planned growth of hydrogen production in the #northsea Around 85% of the national hydrogen network will consist of repurposed natural gas pipelines, which the International Renewable Energy Agency (IRENA) recently estimated could cost 65-94% less than building new hydrogen pipes. The pipelines are expected to become available as less natural gas is transported in the coming years. Netherlands is preparing to shut down the #groningen gas field in late 2023 or early 2024. (11, 12)

PAKISTAN

#Pakistan has granted "comprehensive permission" for the construction of a 400MW #greenhydrogen project that would be powered by 500MW of #windenergy and 700MW of #solarenergy backed up by a battery. (13)

ISLAND

Well said but sometimes the things we seek are already there under our noses. Wind energy is a good contributor but not the solution. Some existing technology developers hold much of the answers to the energy crisis and are ready to contribute today. However due to the small nature of these companies, and lack of resources they find it difficult to rise above the noise & bureaucracy. SEA WAVE ENERGY LIMITED is very serious about energy and can act now! Using the data collected by EMECs Datawell Waverider Buoy, one Waveline Magnet system would be rated at over 100MWh of mechanical power, with the annual equivalent exceeding 140,000MWh or 3,596,000 kg's of Green Hydrogen, at a cost of 0.0251 € / kWh (25.06€/MWh). (14)

UNITED STATES OF AMERICA

Maine, offshore wind process begins through BOEM and hydrogen hub announced by Governor Hochul. Maine and Rhode Island have signed on to a New York-led multi-state agreement, joining with Connecticut, Massachusetts and New Jersey to develop a proposal to become one of at least four regional clean hydrogen hubs designated through the federal Regional Clean Hydrogen Hubs program included in the bipartisan Infrastructure Investment and Jobs Act. Don't wait for the trade press, stay informed through me and with the over 2500 strong community of experts. (15)

CANADA

With abundant offshore wind resources, plentiful storage grade salt formations, and easy access to large European energy markets, Nova Scotia is well suited for large scale green hydrogen production. The declining cost curve of offshore wind power and falling electrolyser prices means large scale production of green fuels will soon be cost competitive with hydrocarbons, allowing Nova Scotia to become a major global player in clean energy production. (16)

AUSTRALIA

The recent announcement of six further offshore wind arrays represents a global market opportunity. Stay informed with the over 2500 strong. (17)

EGYPT

Alfanar Construction (KSA) is sharing glimpses of the green hydrogen MoU signing ceremony in Egypt last week. Witnessed by His Excellency Mostafa Madbouly, Prime Minister of Egypt Mohamed Shaker, Minister of Electricity and Renewable Energy, Hala H. Elsaid Minister of Planning & Economic Development, along with Saudi officials, Faisal A.Alyemni Deputy Minister of Investment, and Mazeed ben Mohammed Al-Hoishan, the Saudi Consul to Egypt. Represented by Alfanar was Mr. Sabah Almutlaq Chairman of Alfanar Global Development Jamal Wadi MD Alfanar Global Development, and Amer Al Ajmi EVP Sales & Marketing at Alfanar Construction. (18)

CHALLENGES & OPPORTUNITIES

In addition to the benefits and positive effects of implementation PTX (P2X) projects to run the decarbonization net zero plans and combat climate change for the current and future

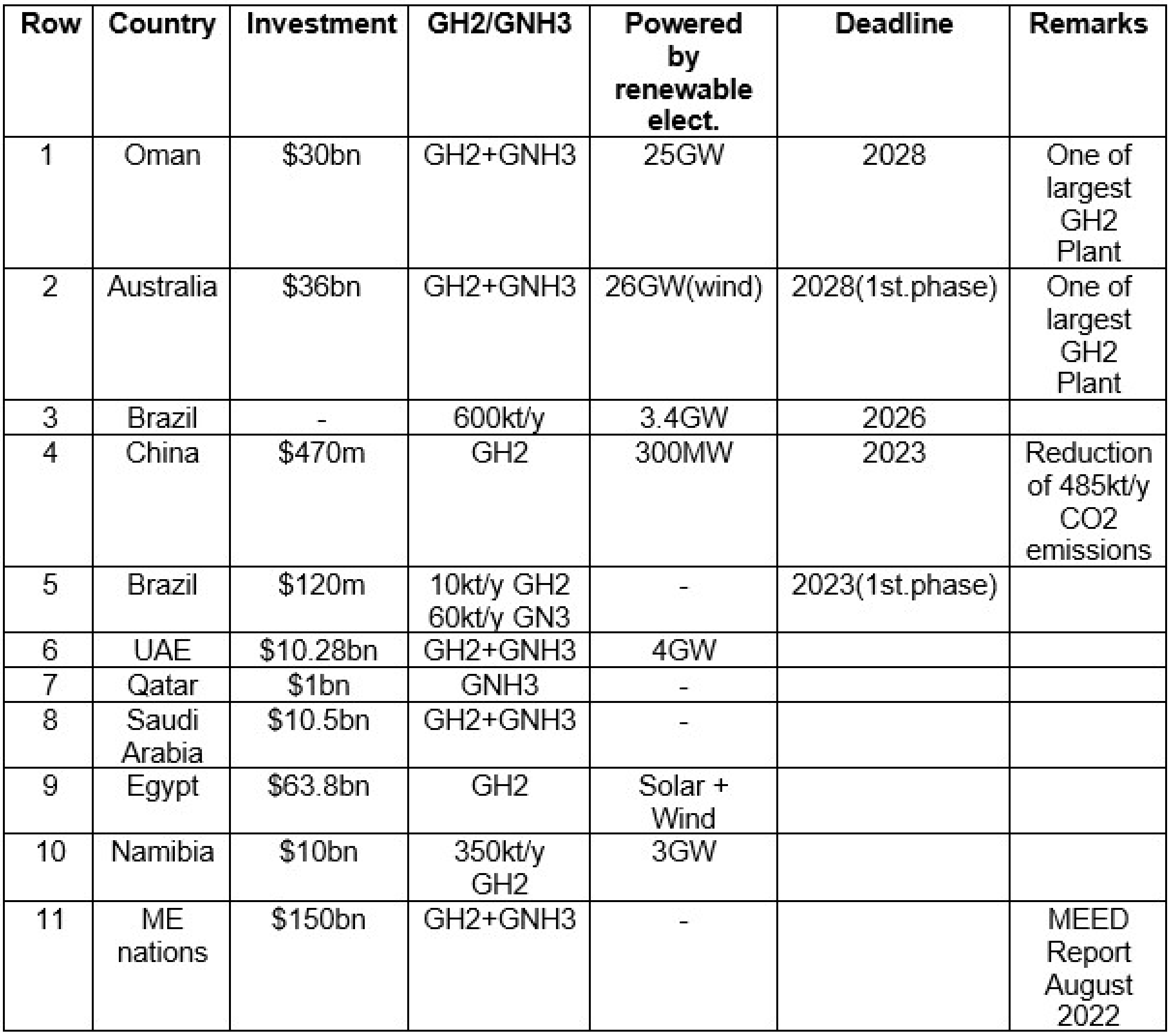
conditions for all countries of the world and the world's environment, there will be challenges such as:

The cost of investing in the production of renewable products

Determining best locations for the construction of renewable electricity production plants especially next to the enough seawater for operation of electrolysis units.

Table 2 shows the amount of investment made by some countries in the Middle East and other countries in the field of green hydrogen and green ammonia production by PTX projects in 2022.

Table 2—Selected P2X Green Hydrogen Projects & Plants in Middle East Area and Other countries (2022)



Row	Country	Investment	GH2/GNH3	Powered by renewable elect.	Deadline	Remarks
1	Oman	$30bn	GH2+GNH3	25GW	2028	One of largest GH2 Plant
2	Australia	$36bn	GH2+GNH3	26GW(wind)	2028(1st.phase)	One of largest GH2 Plant
3	Brazil	-	600kt/y	3.4GW	2026	
4	China	$470m	GH2	300MW	2023	Reduction of 485kt/y CO2 emissions
5	Brazil	$120m	10kt/y GH2 60kt/y GN3	-	2023(1st.phase)	
6	UAE	$10.28bn	GH2+GNH3	4GW		
7	Qatar	$1bn	GNH3	-		
8	Saudi Arabia	$10.5bn	GH2+GNH3	-		
9	Egypt	$63.8bn	GH2	Solar + Wind		
10	Namibia	$10bn	350kt/y GH2	3GW		
11	ME nations	$150bn	GH2+GNH3	-		MEED Report August 2022

CONCLUSION

Considering:

- The control of global warming
- Climate change control by energy transition
- Decreasing trend of non-renewable fossil fuel sources and their becoming more expensive
- Decarbonization
- Net zero emission
- Energy transition

are necessary to go towards the use of clean, renewable fuels substitution and energies in all parts of the world to mitigate and prevent the release of more greenhouse gases. According to the global warming and relevant international conventions of the United Nations (UNFCCC) in this subject, therefore, the need to develop and use P2X technologies in the offshore and onshore areas adjacent to the sea waters will definitely play a valuable and key role in energy transition for the world especially using electrolysis technology.

There are also challenges and opportunities in PTX (P2X) projects, but currently only in the region of Middle East, there are more than 50 projects in this subject constructed or under construction, amounting to 150 billion dollars of investment in which It should be noted that some of these projects are considered to be among the largest PTX technology projects of green hydrogen in the worldwide in 2022.

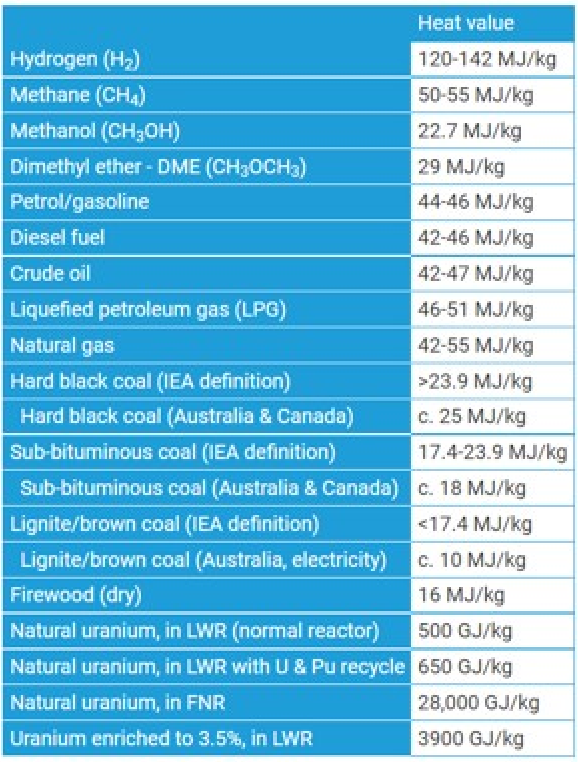
APPENDIX

Appendix A: Heat Values of Various Fuels

The heat value of a fuel is the amount of heat released during its combustion. Also referred to as energy or calorific value, heat value is a measure of a fuel's energy density, and is expressed in energy (joules) per specified amount (e.g. kilograms).

Appendix B: How much hydrogen is produced from 1kg of water electrolysis?

1 liter of water = 1 kg of water. Molar mass of water = 18g, of which H2 = 2g, O = 16g. So 2/18 = 1/9 = 11%. So one liter of water gives 110g of hydrogen gas, which is about 1.3 cubic meters of gas at normal temperature and pressure.



	Heat value
Hydrogen (H_2)	120-142 MJ/kg
Methane (CH_4)	50-55 MJ/kg
Methanol (CH_3OH)	22.7 MJ/kg
Dimethyl ether - DME (CH_3OCH_3)	29 MJ/kg
Petrol/gasoline	44-46 MJ/kg
Diesel fuel	42-46 MJ/kg
Crude oil	42-47 MJ/kg
Liquefied petroleum gas (LPG)	46-51 MJ/kg
Natural gas	42-55 MJ/kg
Hard black coal (IEA definition)	>23.9 MJ/kg
Hard black coal (Australia & Canada)	c. 25 MJ/kg
Sub-bituminous coal (IEA definition)	17.4-23.9 MJ/kg
Sub-bituminous coal (Australia & Canada)	c. 18 MJ/kg
Lignite/brown coal (IEA definition)	<17.4 MJ/kg
Lignite/brown coal (Australia, electricity)	c. 10 MJ/kg
Firewood (dry)	16 MJ/kg
Natural uranium, in LWR (normal reactor)	500 GJ/kg
Natural uranium, in LWR with U & Pu recycle	650 GJ/kg
Natural uranium, in FNR	28,000 GJ/kg
Uranium enriched to 3.5%, in LWR	3900 GJ/kg

Appendix C: Costs of producing hydrogen

While the costs of producing hydrogen range between $2 and $7 per kg globally. The King Abdullah Petroleum Studies and Research Center (KAPSARC) of Saudi Arabia predicted that in the long term, rates of $1 per kg should be reliably attainable in Saudi Arabia, making them easily the cheapest in the world.

Appendix D: PTX technology

What is PtX project?

PtX is the process of converting renewable electricity, from wind and sun, but also from hydro or geo-thermal power plants, into a wide variety (X) of end products. It starts with producing hydrogen in electrolysers using renewable electricity to split water (H2O) into its components hydrogen (H2) and oxygen (O2).

What is a PtX plant?

Power-to-X (PtX) is a next generation renewable energy and storage technology which represents a significant new chapter in large-scale decarbonization of e.g infrastructure and agriculture. The plant will rely on electricity from renewables as sole source of energy.

What is PtX (P2X) hydrogen?

This means that green hydrogen is absolutely essential to a successful energy transition and to achieving international climate goals. It can be used, among other things, to produce climate-neutral fuels. They are called Power-to-X products (PtX). Green hydrogen can also be used to store energy.

What is PtX technology?

Power-to-X technology, (PtX – power to liquid, power to gas or power to ammonia) holds promise as a renewable, non-biogenic technology to produce fuels. PtX uses CO2, water and renewable electricity to produced synthetic liquid hydrocarbon fuels and chemicals.

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Q1 2023 Update for the South East Asia (SEA) O&G Industry

KEY DRIVING FACTORS

Good refining margins push refineries to maximize load and runs.

HIGHLIGHTS

Exxonmobil divest its stake in Sri Racha to Bangchak corp who will now hold 66% stake of the 130KBD refinery. Strong refining margins position the sale of the asset favourably.

Based on operators’ targets for final investment decisions (FIDs), over $16 billion worth of greenfield upstream oil and gas projects could be sanctioned in Southeast Asia in 2023; highest ever from Southeast Asia in a single year. However, 30% of the proposed developments are at high risk of getting delayed. The key risks are the inflation impact on proposed development costs, as well as slow progress on merger and acquisition talks at some projects.

Demand is soaring for oil storage tanks in Singapore, in a sign that a flood of Russian fuel is being blended and re-exported globally. Tank space in the city-state is being snapped up due to a rise in interest and profits from mixing cheap fuel supplies from Russia with shipments from other sources, according to an executive from a tank operator and a consultant who advises traders on the matter. This process can help to obscure the cargoes’ origins, they said.

ST Telemedia Global Data Centres (STT GDC) is investigating the use of cold energy from liquefied natural gas (LNG) transportation to cool a data center in Thailand. When natural gas is transported by sea, it is liquified to reduce its volume, and has to be turned back into gaseus form on arrival for distribution through pipes. Many countries have large regasification plants at major ports, where the LNG becomes a gas again, releasing energy and absorbing heat in the process. This energy usually goes to waste, often simply released into the ocean.

UPCOMING EVENTS

ASEAN Circular Plastics Summit 2023 (29th – 30th March) at Banyan Tree Bangkok, Thailand

Singapore international water week 4-6th June 2023

OGA 19th Asian oil, gas and petrochemicals engineering exhibition Kuala Lumpur Convention Centre 13-15 September 2023

ADIPEC 2-5Oct 2023 Abu Dhabi, UAEASIA ESG & Sustainability Summit was held on 13-14 October 2022.

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