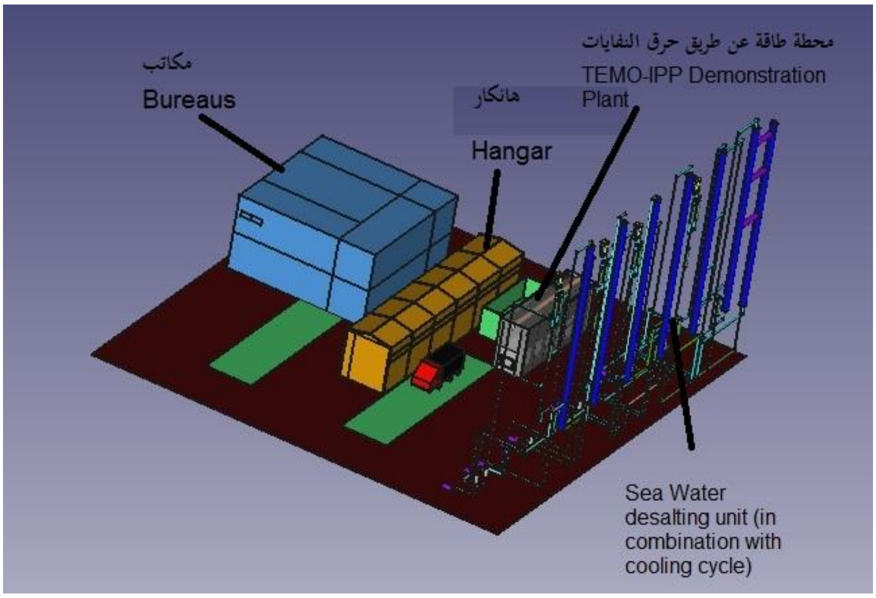
بسم الله الرحمن الرحيم

مصنع لانتاج محطات طاقة كهربائية

المواصفات الفنية

NLAP factory for the production of power plants -Technical Specification



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طاقة الشمال

North Lebanon Alternative Power

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اسم الملف ومكانه

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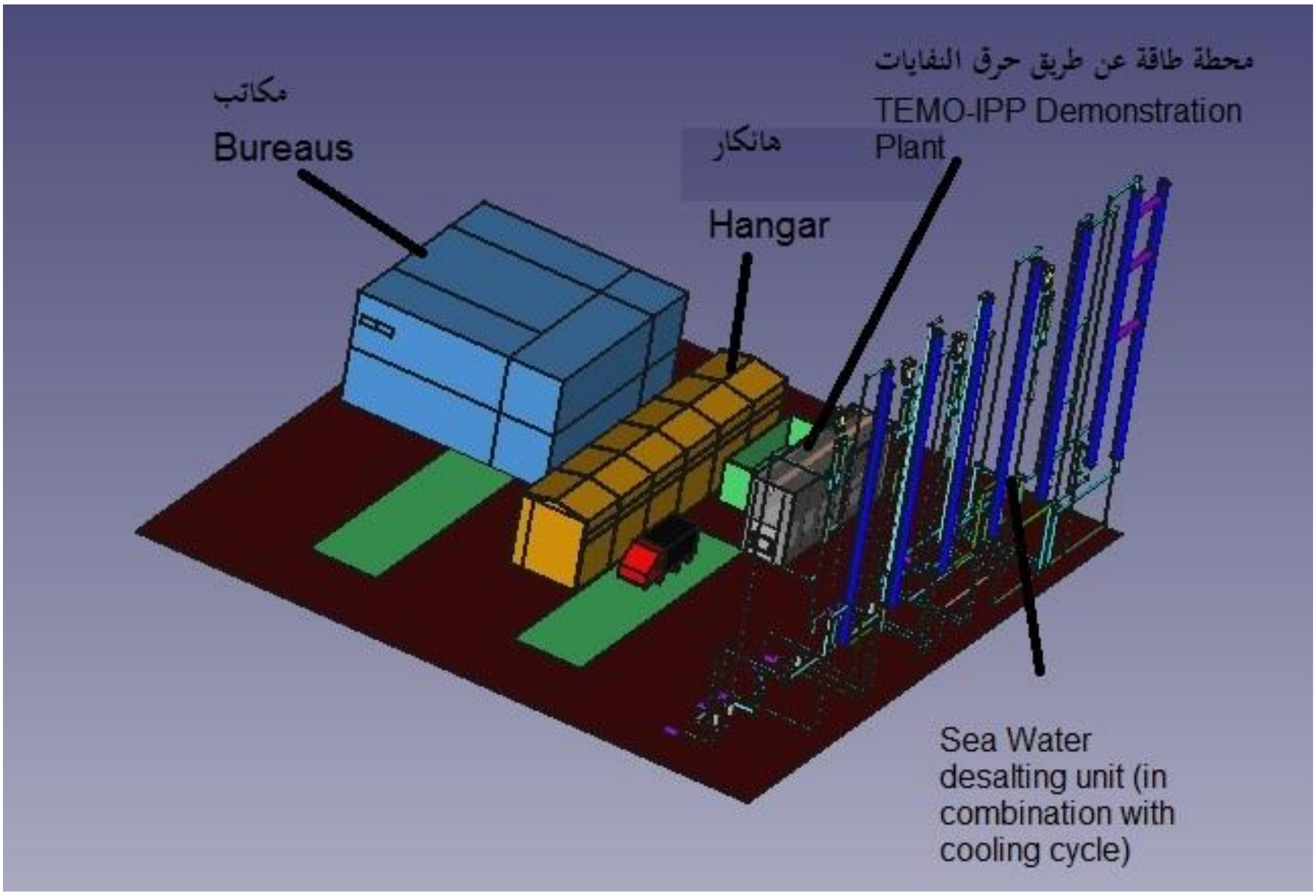
المضمون

Tables

Figures

1 نظرة عامة على منشأة (Overwiew of facility)

1.1 المساحة (Area) 30m x 40m



40m x 40 m = 1600 qm

nlap-facility-13-12-016.fcstd

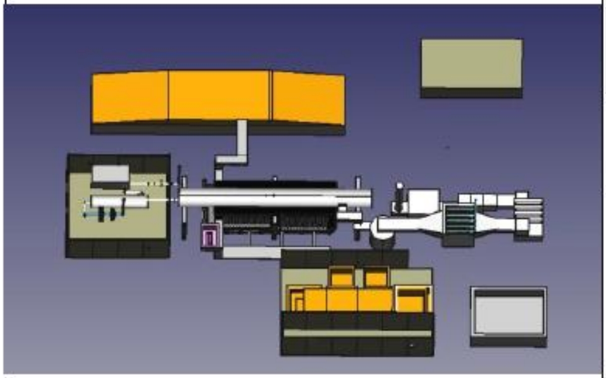
1.2 اجزاء الموقع

The facility has three parts:

- Waste to electricity demonstration cycle
- hangar for production of power plant devices and integration
- bureaus for engineering and administration

NLAP Incineration Demonstration power plant

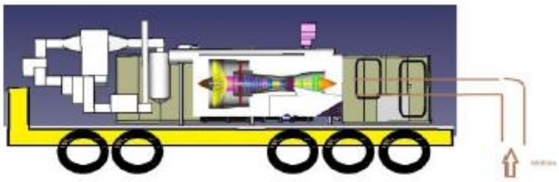
(30 m x 12m= 360 qm)



Water Tank (Cooling)

Desalting unit

Production Hangar (12m x 30 m = 300 qm)



Bureaus (15m x 15 m = 150 qm)

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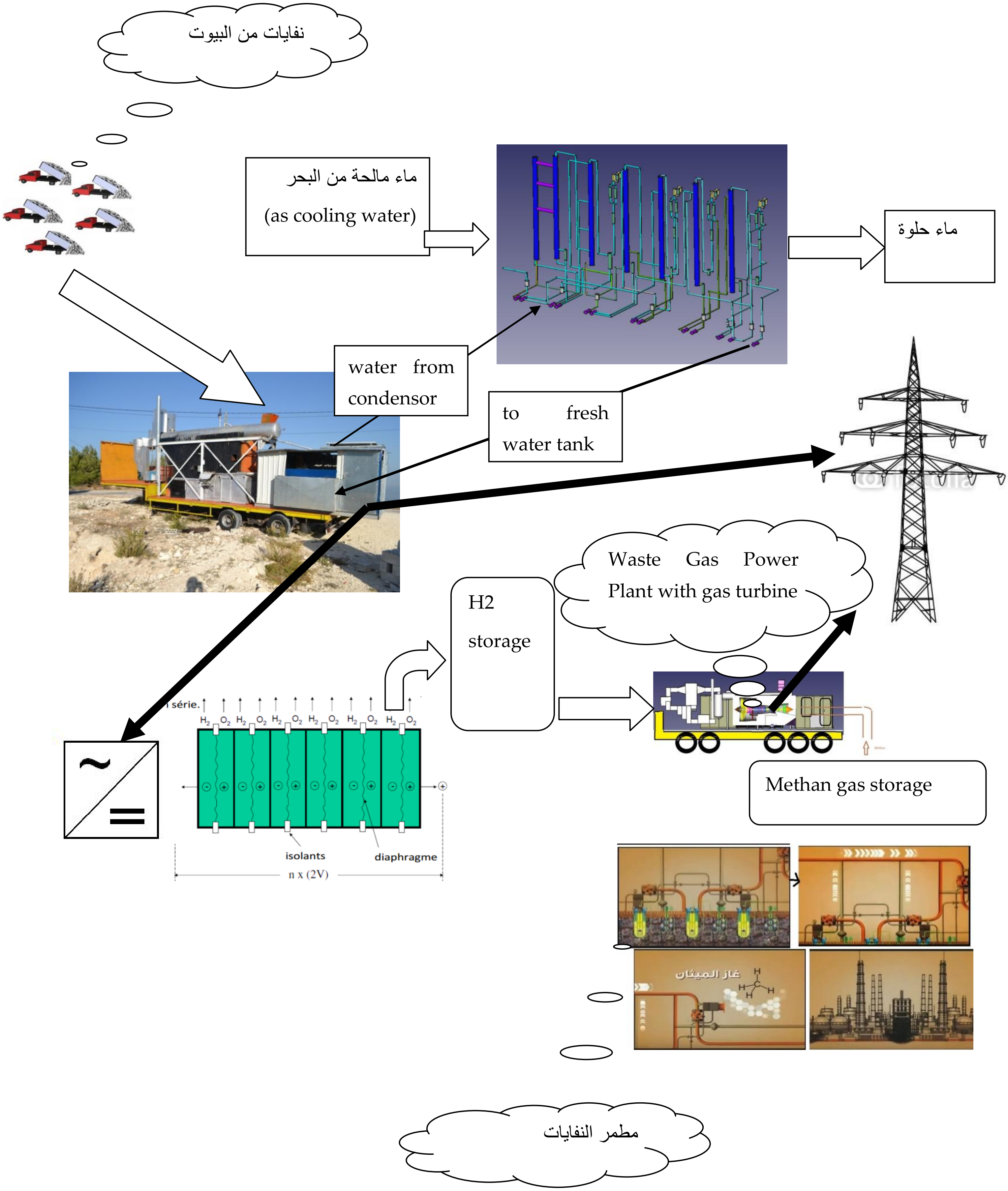
موقع مؤسسة طاقة الشمال

27m x 32 m = 864 qm

1.3 Waste to electricity demonstration cycle



نفايات من البيوت

ماء مالحة من البحر

(as cooling water)

ماء حلوة

water from condensor

to fresh water tank

Waste Gas Power Plant with gas turbine

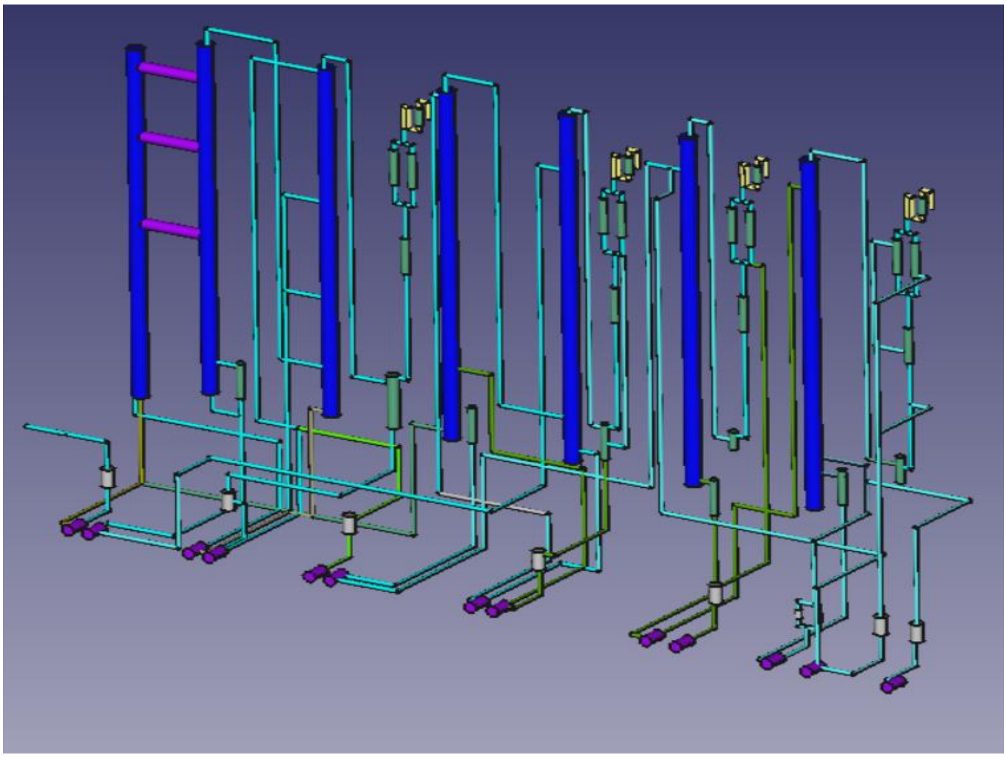
H2 storage

Methan gas storage

مطمر النفايات

2 محطة طاقة تجاربية عن طريق حرق النفايات TEMO-IPP

3 محطة تحلية المياه (Desalting unit)

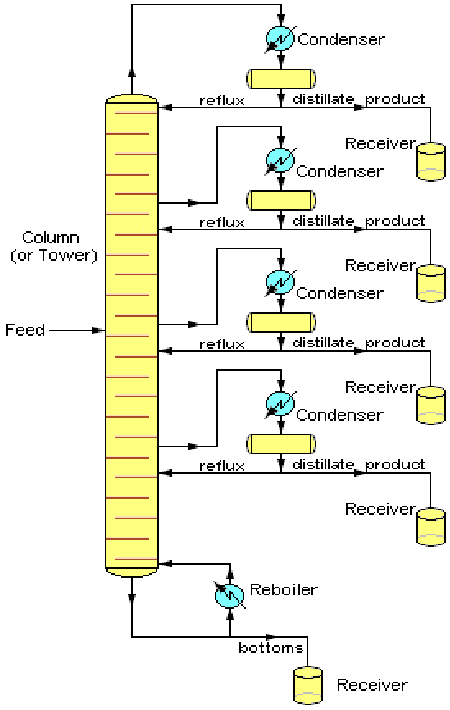


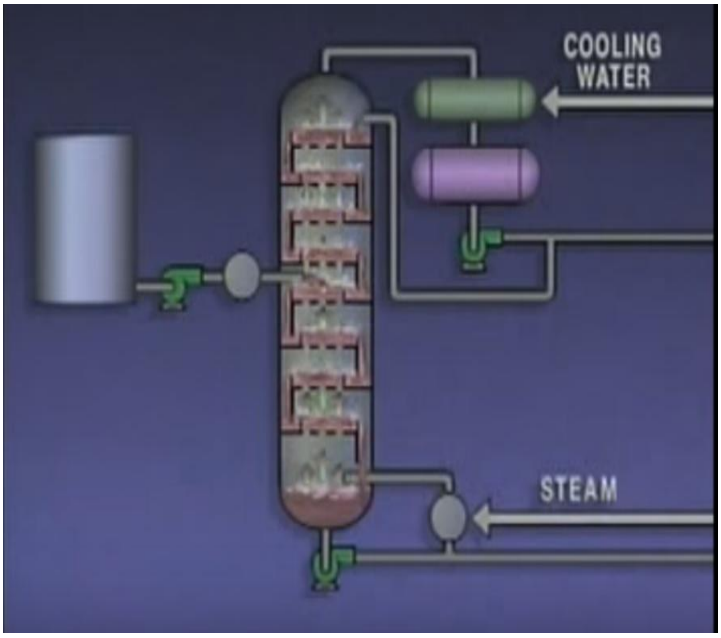
3.1 *التقطير المستمر* (Continuous distillation)

Continuous distillation is an ongoing separation process in which a liquid mixture of two or more miscible components is continuously fed into the process and physically separated into two or more products by preferentially boiling the more volatile (i.e., lower boiling point) components out of the mixture.

التقطير المستمر (Continuous distillation) هي عملية تقطير مستمرة حيث يمون عامود التقطير باستمرار بمخلوط السوائل في حين استخلاص وفصل جزء أو أجزاء من السوائل المقطرة النقية. وتتسم عملية التقطير بفصل مكونات مخلوط من السوائل بواسطة اختيار درجة غليان وتكثيف البخار. ويتكون المخلوط من سائلين أو أكثر تختلف درجة غليان كل منها عن الأخرى، وبالتالي تختلف تطايرية كل منها. عند تسخين المخلوط يبدأ أولا السائل ذو درجة غليان منخفضة في الغليان وينفصل في هيئة بخاره. يصعد البخار في عامود التقطير ويتكثف، بينما تبقى المكونات القليلة التطاير في قاع العامود.

3.2 أجزاء التقطير المستمر (Parts of continuous distillation)





Industrial distillation is typically performed in large, vertical cylindrical columns (see the adjacent photographs) commonly referred to as *distillation columns*, *distillation towers* or *fractionators* with diameters ranging from **about 65 centimeters to 11 meters** and heights ranging from about 6 meters to 60 meters or more.

To provide for the intimate mixing of the upward flowing vapor and downward flowing liquid in distillation columns, the columns usually contain a series of horizontal distillation trays or plates .The distillation trays or plates are typically separated by about **45 to 75 centimetres of** vertical distance. However, some columns are designed to use beds of packing media rather than trays or plates.

To prevent scaling, pre-treatment of sea water can be carried out by adding polyphosphates or sulfuric acid, adding small balls of sponge, recovered at the outlet, which continuously clean tubes and tanks or It is also possible to add to the brine seed crystals on which the tartar is preferentially deposited (so-called germination method).

On the other hand, one of the main problems of distillation multiple effects after scaling is corrosion due to large amounts of chloride ions in seawater (ions increase the conductivity of water and Thus accelerating corrosion.) Materials or coatings are used which significantly increase the cost of the installations and help to limit the number of effects used.

لمحاربة التحجم، يمكن للمرء أن تعمل على المعالجة من مياه البحر عن طريق إضافة فوسفات أو حمض الكبريتيك، إضافة كرات صغيرة من انتاج الاسفنج استردادها، الذي تنظيف مستمر الأنابيب والخزانات أو مازال إضافة بلورات البذور الماء المالح الذي تفضل الجير المودعة (المعروف طريقة الإنبات).

من ناحية أخرى، واحدة من المشاكل الرئيسية للتأثير التقطير المتعدد، بعد التحجيم، هو التآكل بسبب كميات كبيرة من أيونات الكلوريد في مياه البحر (أيونات زيادة التوصيل من الماء و وبالتالي تسريع التآكل.) هو مطلوب منها لاستخدام مواد أو الطلاء الذي رفع بشكل كبير من تكلفة المرافق ويساعد على الحد من عدد من الآثار المستخدمة.

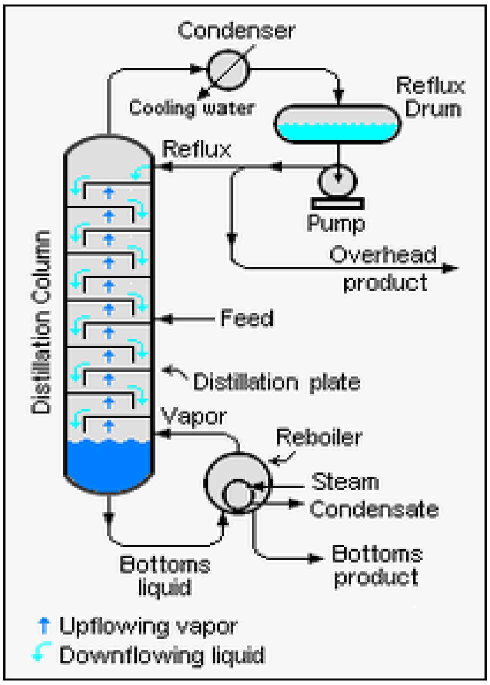


Figure 1: *Schematic diagram of a continuous binary distillation column.*

The design of a distillation column depends upon the composition and the thermal condition of the feed as well as the composition of the desired products. The McCabe-Thiele method and the Fenske equation may be used to design a simple binary distillation column (as in Figure 1).

To design a column for the distillation of a multi-component feed to provide more than two product distillates , computerized simulation models may be used for the design as well as for the subsequent online operation of the column.

Many industrial uses of continuous distillation operate **24 hours per day for as long as 2-5 years between** routine, scheduled maintenance shutdowns. The operational control of a distillation column may be performed by advanced computer control systems but highly experienced workers are still required to oversee the online, real time operations and to provide daily routine maintenance as needed.

3.3 عمود التغذية (Column feed)

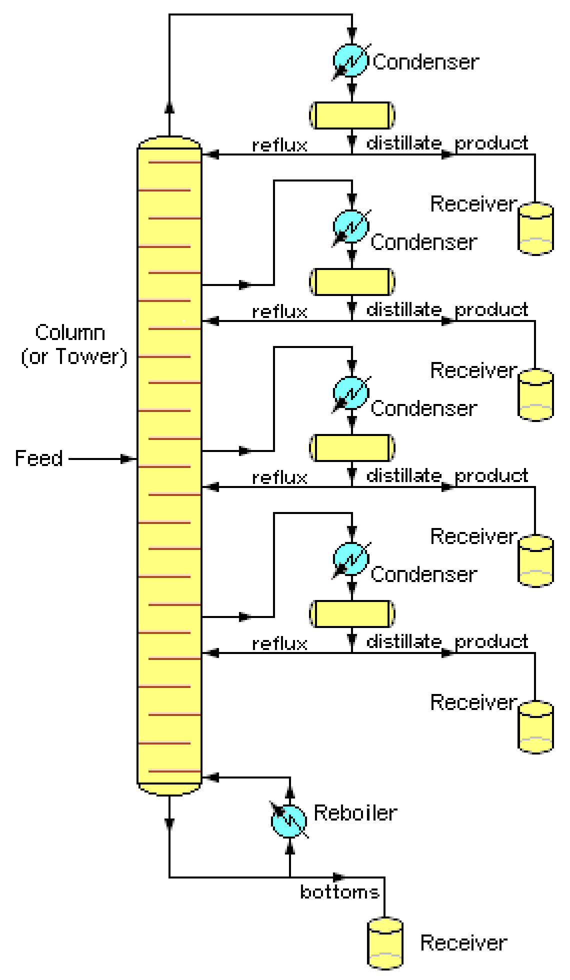


Figure2: Simplified chemical engineering schematic of Continuous Fractional Distillation tower separating one feed mixture stream into four distillates and one bottoms fractions

Indeed to transform one kg of liquid water into 1 kg of steam water at the same temperature it takes about 2250 kilojoules

The manner of feeding a continuous column depends upon the column pressure and the pressure of the feed source. If the feed is from a source at a pressure sufficiently higher than the column pressure, it may be simply piped into the column at the designated feed entry point. A liquid feed from a source at a lower pressure than the column needs to be pumped into the column, and a gas feed from a source at a lower pressure than the column needs to be compressed to a higher pressure before entering the column.

The feed may be a superheated vapor, a saturated vapor, a partially vaporized liquid-vapor mixture, a saturated liquid or a sub-cooled liquid. If the feed is a saturated liquid at a higher pressure than the column pressure and flows through a valve just before entering the column, it will undergo a flash vaporization (also known as an *equilibrium flash* or a *throttling expansion*) resulting a liquid-vapor mixture as it enters the column.

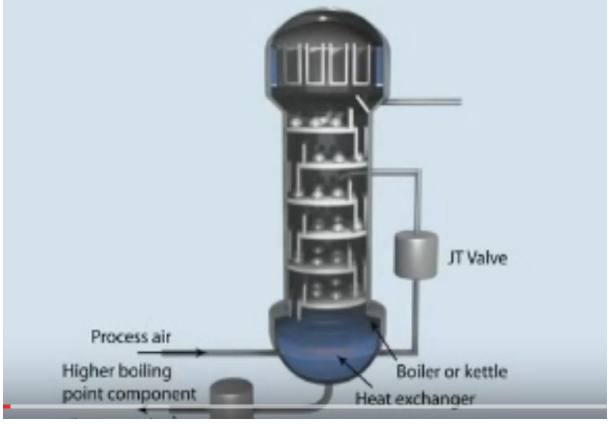
3.4 //التبخير (Overhead vaporization system)

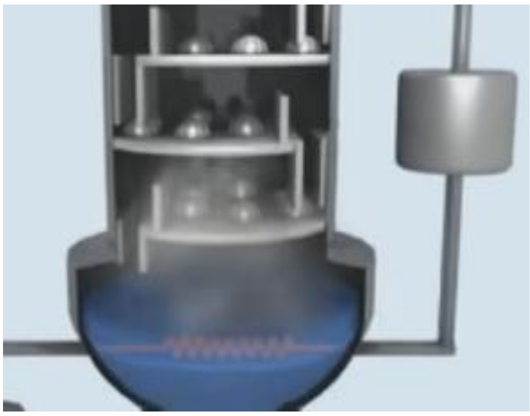
Figures 1 and 2 are based on the assumption that the overhead vapor from a distillation column is cooled and totally condensed in a water or air-cooled condenser. However, in many cases, the tower overhead can’t be totally condensed with a typical air or water-cooled condenser and therefore the reflux drum must include a gas vent for the uncondensed vapor.

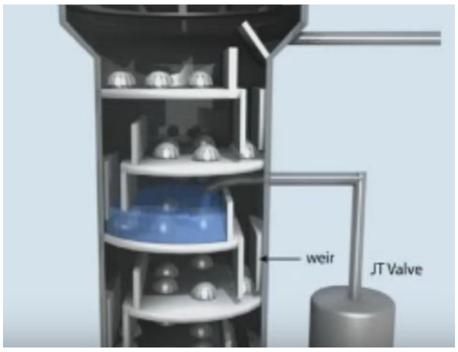
In yet other cases, the overhead stream may also include water vapor because either the feed contains some water or because some steam is injected into the distillation column (which is the case with crude oil distillation towers in petroleum refineries, shown in Figure 4). In those cases, if the overhead distillate product is immiscible in water, the reflux drum may contain a condensed liquid distillate phase, a condensed water phase and a non-condensable gas phase, which makes it necessary that the reflux drum also have a water separation section

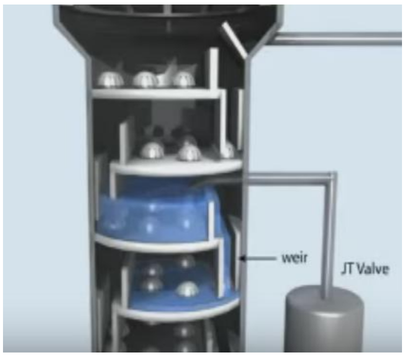
We can view in this following pictures the step to entrance of feed .

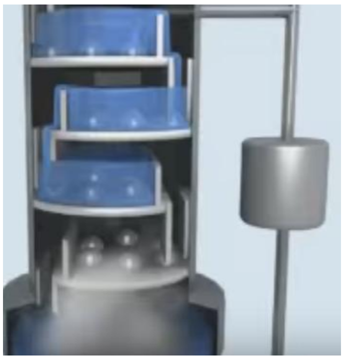
Une telle installation se compose, notamment, d'un condenseur - évaporateur (1), du cylindro-flash (CF), d'une chaudière (2), d'un couloir d'eau distillée (24), d'un circuit d'extraction de gaz (7), d'un circuit d'eau d'appoint (3), d'un circuit de traitement chimique de l'eau de mer (5) et d'un circuit de traitement chimique de l'eau distillée .

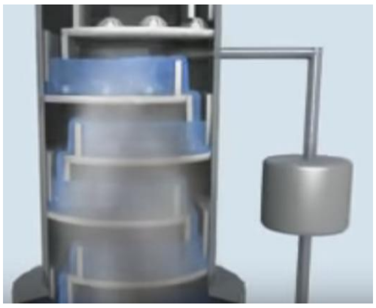


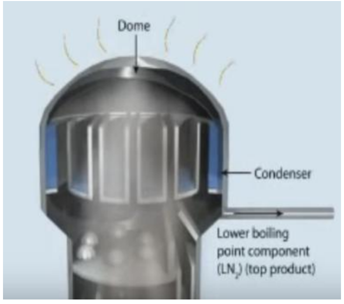


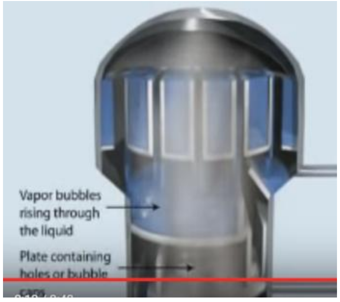




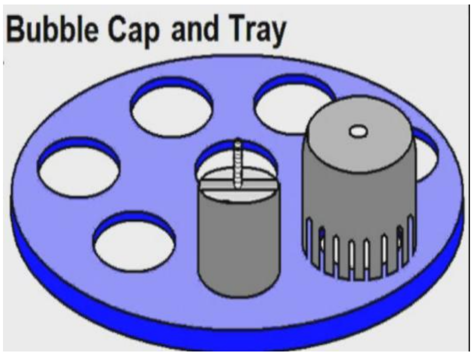


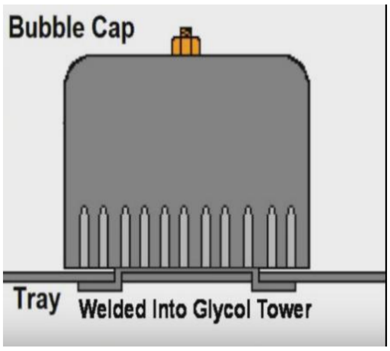


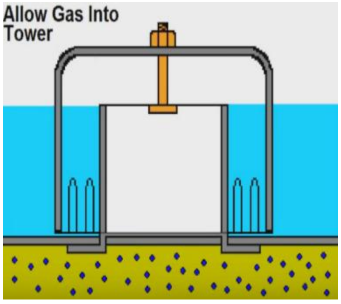


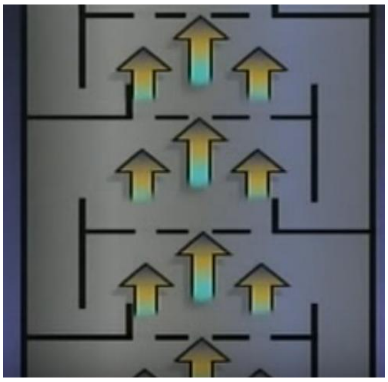


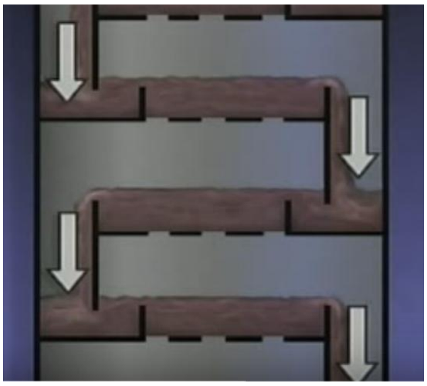
Bubbles to horizontals plat in column:

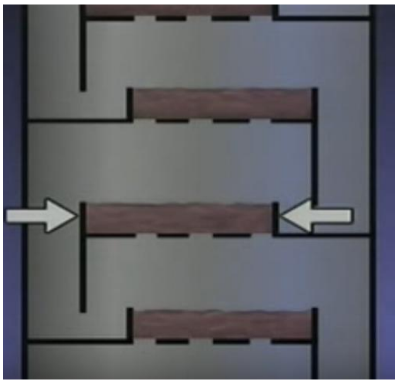


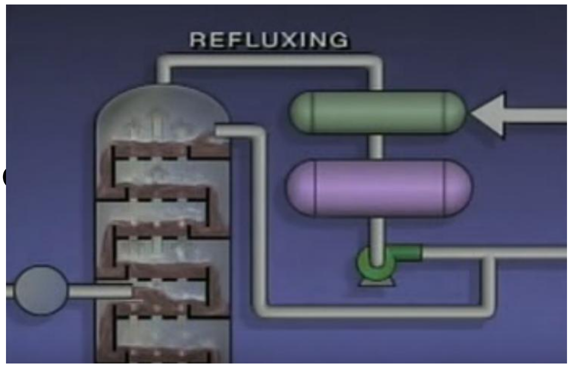


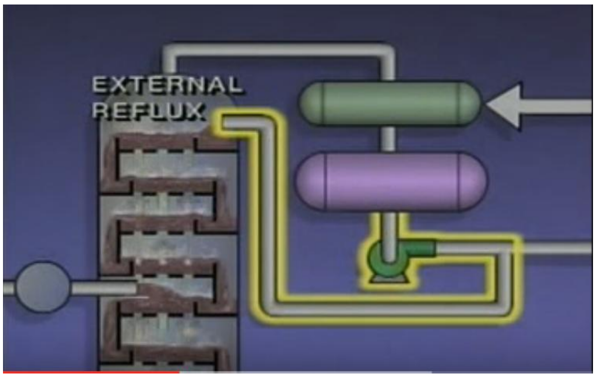


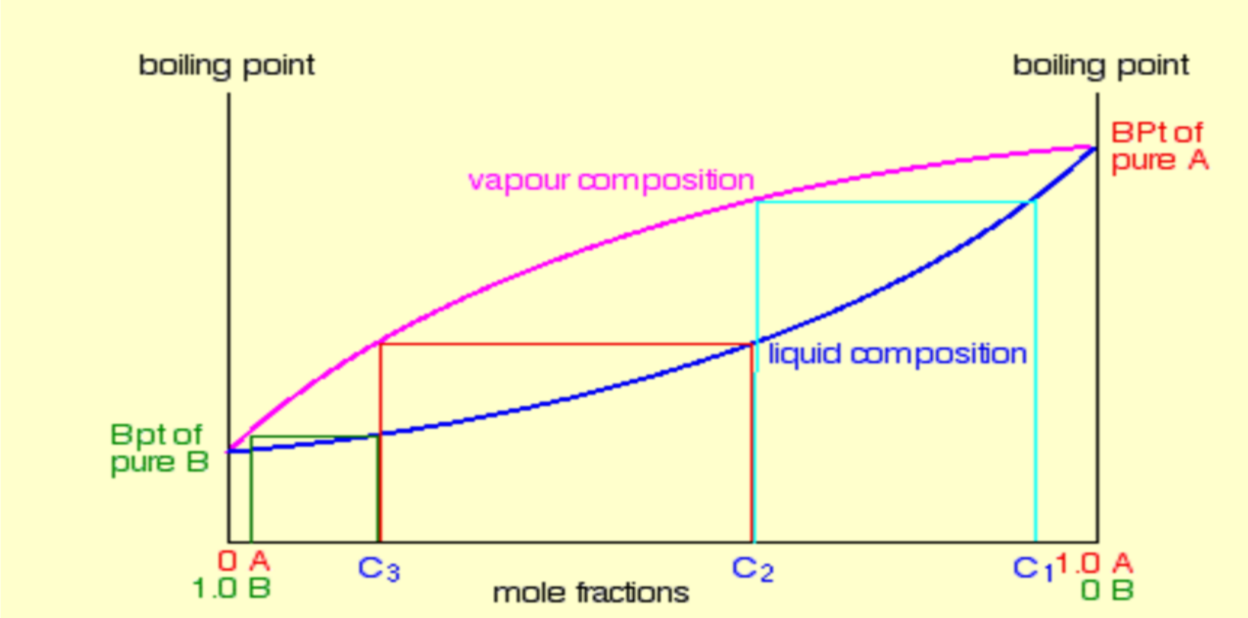












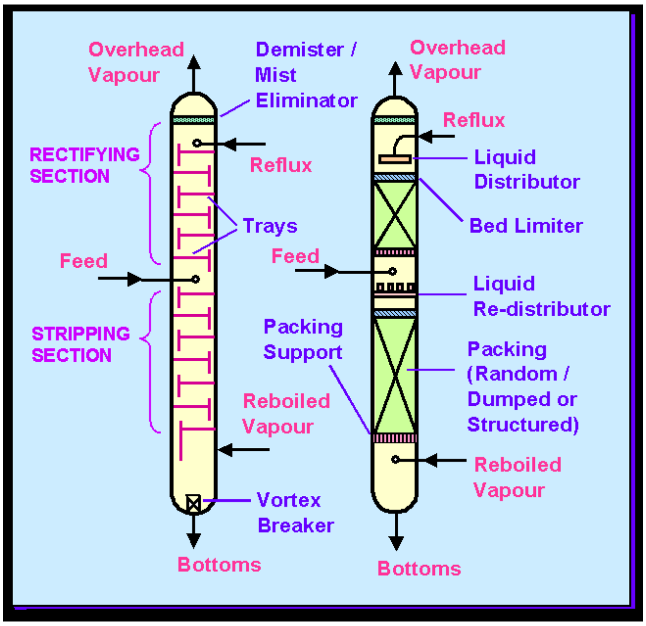
If you boil a liquid mixture C_1, you will get a vapor with composition C_2, which you can condense to give a liquid of that same composition (the pale blue lines).

If you reboil that liquid C_2, it will give a vapor with composition C_3. Again you can condense that to give a liquid of the same new composition (the red lines).

Reboiling the liquid C_3 will give a vapor still richer in the more volatile component B (the green lines). You can see that if you were to do this once or twice more, you would be able to collect a liquid which was virtually pure B.

The secret of getting the more volatile component from a mixture of liquids is obviously to do a succession of boiling-condensing-Reboiling operations.

It isn't quite so obvious how you get a sample of pure A out of this. That will become clearer in a while. (2)



(3)

3.4.1 The energy needed to heat the water

We need 1 Kcal to increase the temperature 1 °C of 1 m^3 of water (1000 L)

1 Kcal=1.16 wh

Thus, to increase the temperature ,it's necessary for example:

If Tinput=15°C,(100-15=85°C)

We need 85 Kcal *1000 L*1.16wh=98.6 Kwh

Or the vaporization :

1 L of water → 2256.10^{3}J

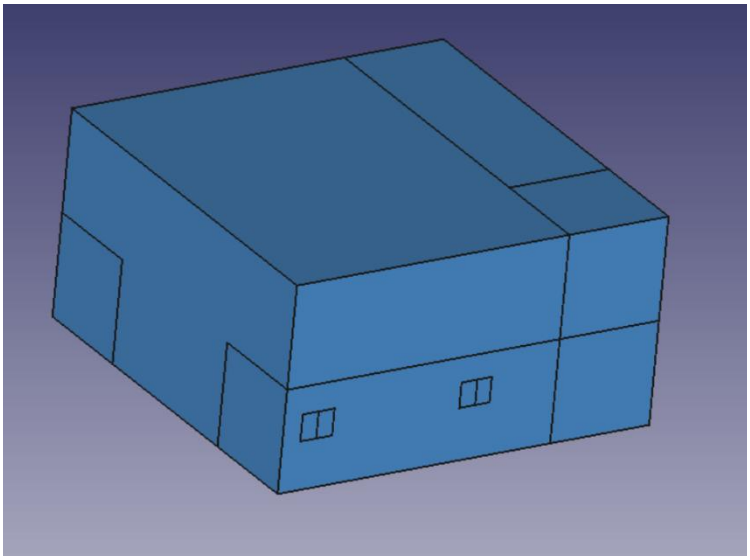
Hence,2256.10^3 Kj TO 1 m^3 water

Or 1wh=3600 J → power=2256 KJ*wh/3600J=627 kwh

3.4.2 تحذيرات للأمان (Safety)

1. eye protection must be worn
2. foot protection must be worn in this area
3. do not use mobile telephone
4. caution hot surface

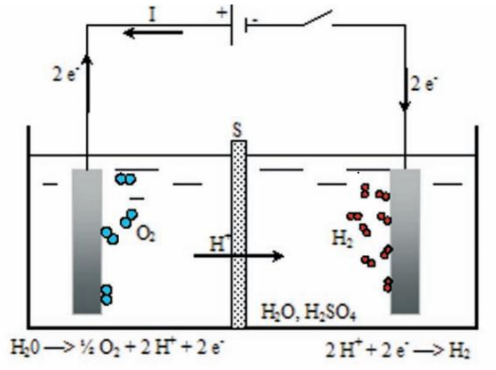
4 المكتب (office)



5 تحليل الكهربائي للماء (electrolysis of water)

التحليل الكهربائي هو أسلوب يستخدم الماء (H_2O) كمادة خام لإنتاج الهيدروجين وغاز الأكسجين من خلال تيار كهربائي ومع ذلك، إلا أن التكنولوجيا الكهربائي قلوية ناضجة اليوم ويجلب التنافسية الاقتصادية مع تقنيات إنتاج الهيدروجين التقليدية مع بصمة الكربون يرثى لها احتراق الهيدروجين تنتج حوالي 3 مرات اكثر من الطاقة حارقة على وزن ثابت انخفاض درجة الحرارة الكهربائي (<200 درجة مئوية) باستخدام محلول مائي القلوية حمض الكبريتيك (H_2SO_4) أو هيدروكسيد البوتاسيوم(KOH) ؛

The decomposition of water by electrolysis is written in a global manner:



$H_2O \rightarrow H_2 + \frac{1}{2} O_2$

With an enthalpy of dissociation of water: ΔH = 285 kJ / mole.

This decomposition requires a supply of electrical energy, essentially dependent on the enthalpy and the entropy of reaction. The theoretical potential of the decomposition is 1.481 V at 298 K. Typical values industrial cell potential is in the order of 1.7 to 2.1 V, which corresponds to electrolysis yields of 70 to 85% (by Relative to the PCS of 3.55 kWh / Nm3). The electrical consumption of industrial electrolyzers (including auxiliaries) is generally 4 to 5 kWh / Nm3. It should be noted that the heat generated by irreversibilities must be permanently eliminated.

The minimum water supply of an electrolyser is 0.8 l / Nm3 of hydrogen. In practice, the actual value is close to 1 l / Nm3. The introduced water must be as pure as possible because the impurities remain in the equipment and accumulate in the course of the electrolysis, ultimately disturbing the electrolytic reactions by:

- sludge formation
- the action of chlorides on the electrodes

An important specification on water relates to its ionic conductivity (which must be less than a few μS / cm).

An electrolytic cell consists of two electrodes (anode and cathode, electronic conductors) connected to a DC generator, and separated by an electrolyte (ionic conductive medium).

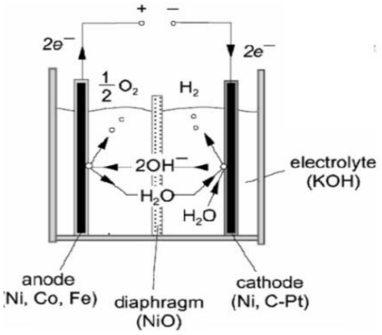
This electrolyte can be:

- Or an acidic or basic aqueous solution,
- Or a proton exchange polymer membrane
- Or a ceramic membrane conductive of O 2 ions.

There are many suppliers offering very diversified technologies, in particular in terms of the nature of the electrolyte and associated technology, ranging from a possible upstream coupling with a renewable electricity supply (photovoltaic or wind), to the Direct final supply of hydrogen under pressure. The combustion of hydrogen generates about 3 times more energy than gasoline at constant weight.

Low alkaline (<200 ° C) alkaline electrolysis using an aqueous solution of sulfuric acid (H2SO4) or potassium hydroxide (KOH); (2)

5.1 Alkaline electrolysis



Electrolyte : 30% KOH
Température de fonctionnement : 70-80 °C
Pression de fonctionnement : < 30 bar

Figure 2: Alkaline electrolysis

anode : 2 OH- → ½ O2 + H2O + 2 e-
cathode : $\mathbf{2\ H_2 + 2\ e^- \rightarrow H_2 + 2\ OH^-}$

Alkaline electrolysis is the most widely used process in the industry and therefore

mature.

• Electrolysers are in peak or medium capacity modules

(0.5-800 Nm 3 / h of hydrogen),

• using an aqueous solution of potassium hydroxide (or potassium hydroxide)

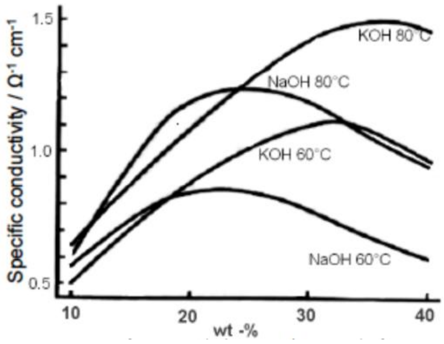
Concentration varies depending on the temperature (typically 25% in

Mass at 80 ° C up to 40% at 160 ° C).

• Potash is preferred to soda, essentially for

Higher conductivity at equivalent temperature and better

Control of chloride and sulphate impurities.



The concentration varies depending on the operating temperature

To maximize electrical conductivity:

25% by weight for a temperature of 80 to 90 ° C;

30 to 35% at 120 ° C;

- 40% at 160°C.

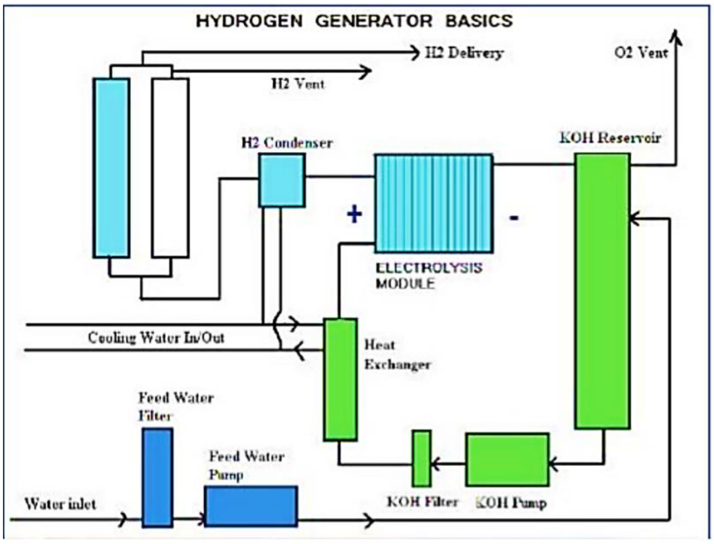
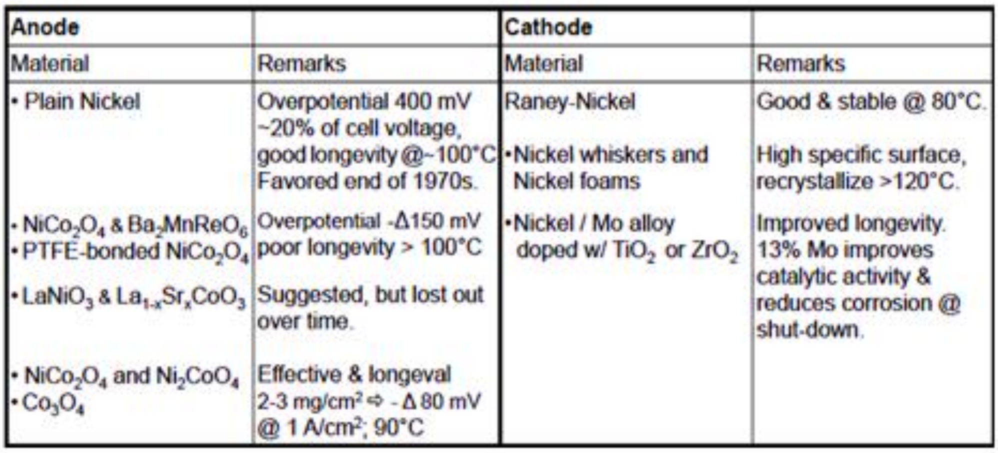


Figure 3:hydrogen generator

The anodes are made of nickel-plated steel at a temperature of

Function below 90 °C, and solid nickel beyond. The cathode is consisted of iron (up to 100 ° C.) with a surface deposit of nickel or a nickel-base alloy (Ni-S, Ni-Zn ...) to reduce Power surges



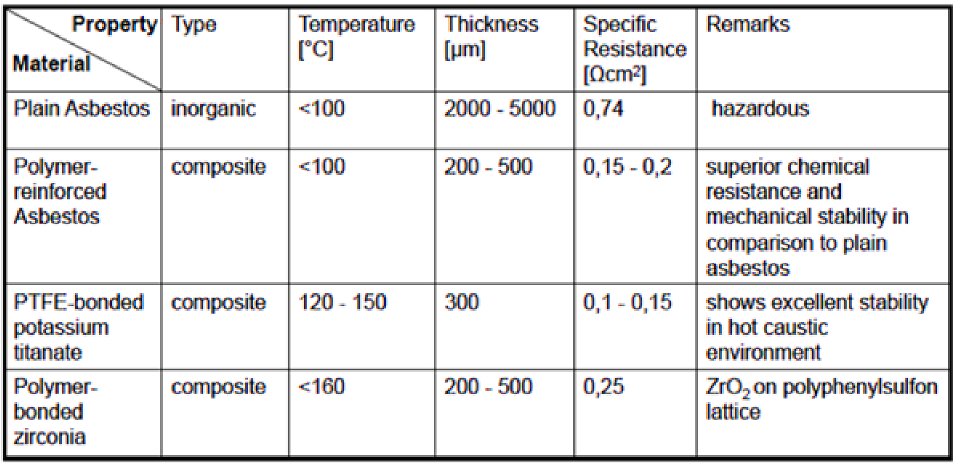
Anode		Cathode	
Material	Remarks	Material	Remarks
• Plain Nickel	Overpotential 400 mV ~20% of cell voltage, good longevity @~100°C Favored end of 1970s.	Raney-Nickel •Nickel whiskers and Nickel foams	Good & stable @ 80°C. High specific surface, recrystallize >120°C.
• $NiCo_2O_4$ & Ba_2MnReO_6 • PTFE-bonded $NiCo_2O_4$	Overpotential -Δ150 mV poor longevity > 100°C	•Nickel / Mo alloy doped w/ TiO_2 or ZrO_2	Improved longevity. 13% Mo improves catalytic activity & reduces corrosion @ shut-down.
• $LaNiO_3$ & $La_{1-x}Sr_xCoO_3$	Suggested, but lost out over time.		
• $NiCo_2O_4$ and Ni_2CoO_4 • Co_3O_4	Effective & longeval 2-3 mg/cm² ⇨ - Δ 80 mV @ 1 A/cm²; 90°C		

Table 1:technical alkaline concepts

- the maximum operating temperature resulting from a compromise between the Overvoltages and corrosion resistance of materials used

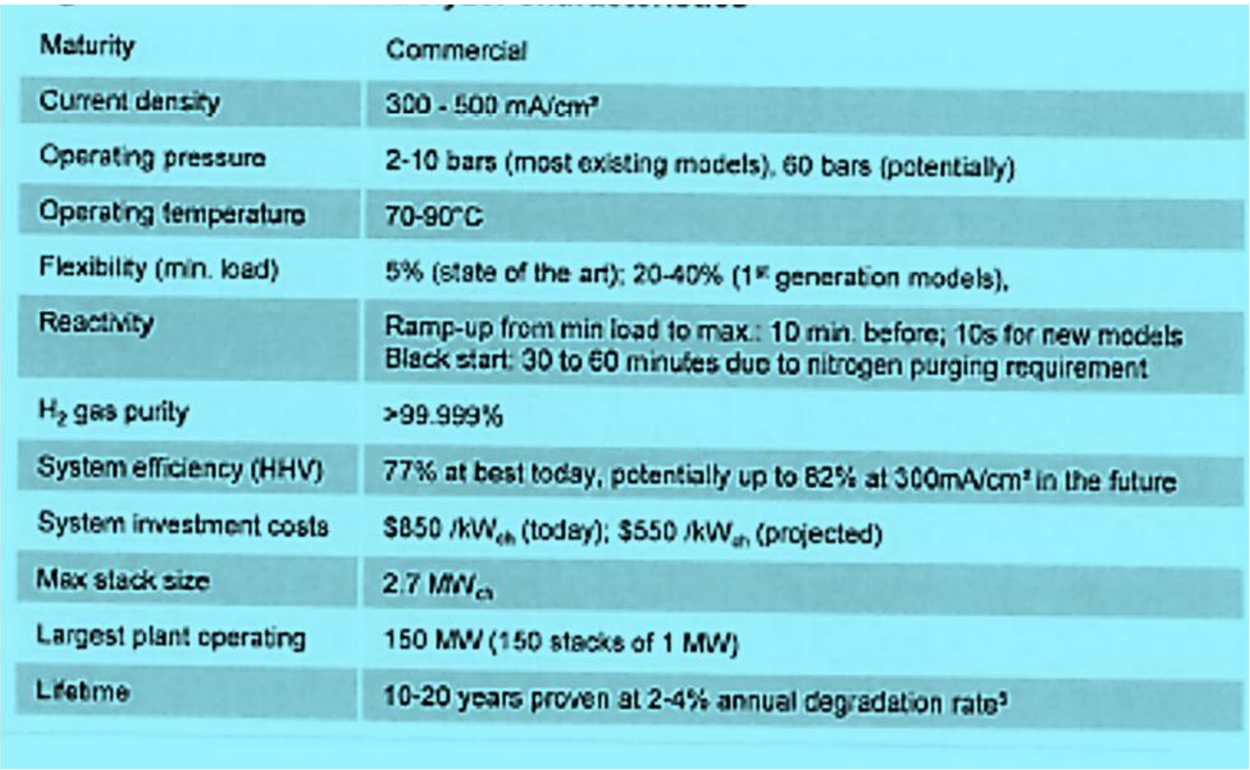
The concentration of the electrolyte, defined by the conductivity opmum at the temperature Considered

- the rapid circulation of the electrolyte makes it possible to avoid deviations of concentration
- The geometry of the electrodes to facilitate the elimination outside the electric field of Bubbles formed;
- the use of split electrodes (fripped metals) reducing overvoltages by one Local increase in area active
- the diaphragm which must introduce the least possible drop of ohmic, (thin thickness, Of high porosity, of a small average pore diameter (<1 μm).



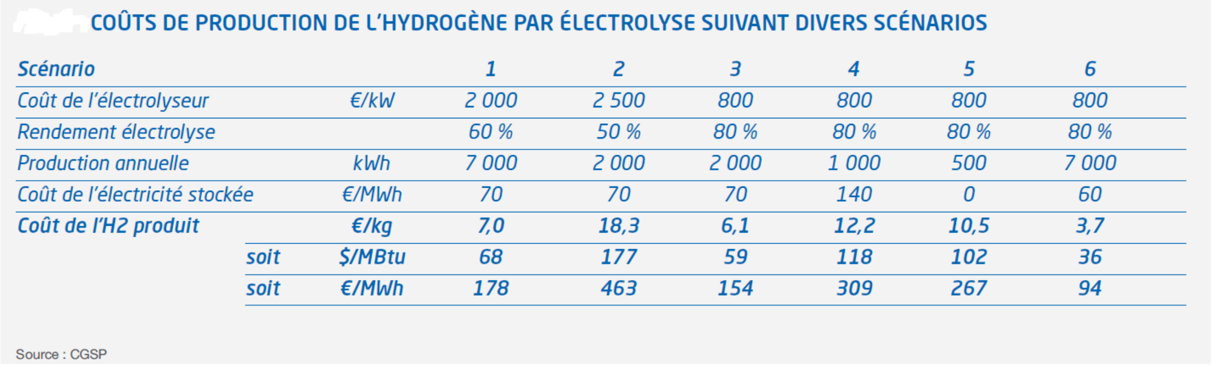
Property **Material**	Type	Temperature [°C]	Thickness [μm]	Specific Resistance [Ωcm^2]	Remarks
Plain Asbestos	inorganic	<100	2000 - 5000	0,74	hazardous
Polymer-reinforced Asbestos	composite	<100	200 - 500	0,15 - 0,2	superior chemical resistance and mechanical stability in comparison to plain asbestos
PTFE-bonded potassium titanate	composite	120 - 150	300	0,1 - 0,15	shows excellent stability in hot caustic environment
Polymer-bonded zirconia	composite	<160	200 - 500	0,25	ZrO_2 on polyphenylsulfon lattice

Table 2:technical concepts for alkaline electrolysers/diaphragms



Maturity	Commercial
Current density	300 - 500 mA/cm²
Operating pressure	2-10 bars (most existing models), 60 bars (potentially)
Operating temperature	70-90°C
Flexibility (min. load)	5% (state of the art); 20-40% (1st generation models),
Reactivity	Ramp-up from min load to max.: 10 min. before; 10s for new models Black start: 30 to 60 minutes due to nitrogen purging requirement
H_2 gas purity	>99.999%
System efficiency (HHV)	77% at best today, potentially up to 82% at 300mA/cm² in the future
System investment costs	\$850 /$\mathrm{kW_{el}}$ (today); \$550 /$\mathrm{kW_{el}}$ (projected)
Max stack size	2.7 $\mathrm{MW_{el}}$
Largest plant operating	150 MW (150 stacks of 1 MW)
Lifetime	10-20 years proven at 2-4% annual degradation rate[3]

Figure 4: Three units of 2 MW Enertrag alkaline electrolyser unit - 1000 m3 / h



COÛTS DE PRODUCTION DE L'HYDROGÈNE PAR ÉLECTROLYSE SUIVANT DIVERS SCÉNARIOS

Scénario			1	2	3	4	5	6
Coût de l'électrolyseur		€/kW	2 000	2 500	800	800	800	800
Rendement électrolyse			60 %	50 %	80 %	80 %	80 %	80 %
Production annuelle		kWh	7 000	2 000	2 000	1 000	500	7 000
Coût de l'électricité stockée		€/MWh	70	70	70	140	0	60
Coût de l'H2 produit		**€/kg**	**7,0**	**18,3**	**6,1**	**12,2**	**10,5**	**3,7**
	soit	**$/MBtu**	**68**	**177**	**59**	**118**	**102**	**36**
	soit	**€/MWh**	**178**	**463**	**154**	**309**	**267**	**94**

Source : CGSP

Figure 5: Costs of production according to various scenarios detailed below

5.2 Alkaline Technology

- IHT, Industrie Haute Technologie, (Switzerland) - electrolysers from 20 to 760 Nm3 / h, from 1 to 32 bar, http://www.iht.ch/technologie/electrolyse/industry/electrolyse-sous-haute-pression-systeme-lurgi.html
- ELT - Elektrolyse Technik GmbH, (Germany): electrolyzers from 330 to 1400 Nm3 / h, from 1 to 30 bar (Figure 10), http://www.elektrolyse.de
- Hydrogenics, (Canada) ex-Vandenborre / Stuart Energy, produces the family of electrolysers, HySTAT from 10 to 15 Nm3 / h, 10-25 bar, http://www.hydrogenics.com/
- Angstrom Advanced Inc. (USA) - electrolysers, up to 500 Nm3 / h, up to 50 bar, http://www.angstrom-advanced.com/index.asp?page=hydrogenh2o

5.3 Technologies: Monopolar and bipolar structures

The first electrolysis apparatus had mono-polar electrodes (i.e., That each anode is connected to the pole positive and each cathode to the pole negative), the Electrolysis cells then function in parallel.

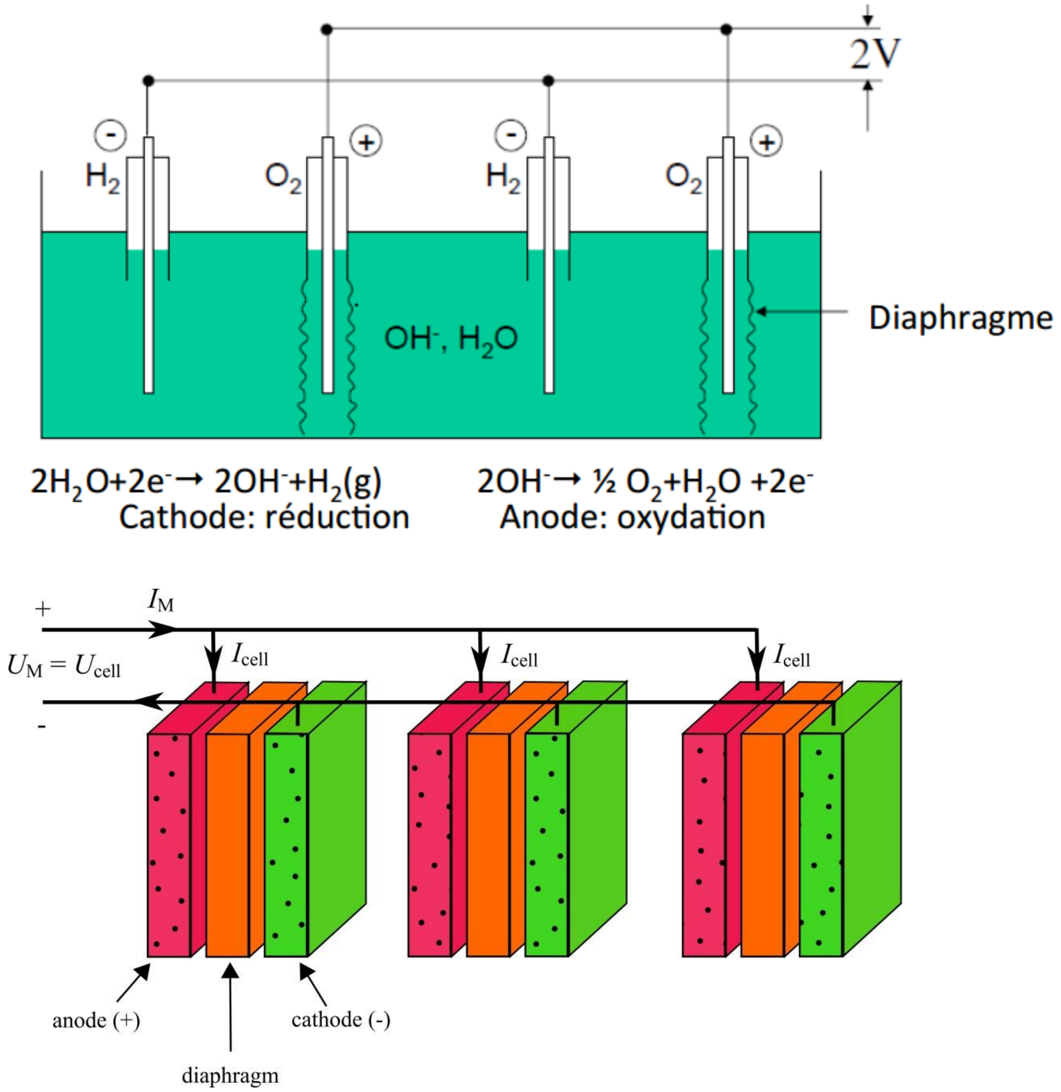


Figure 6:Alkaline Monopolar with tank

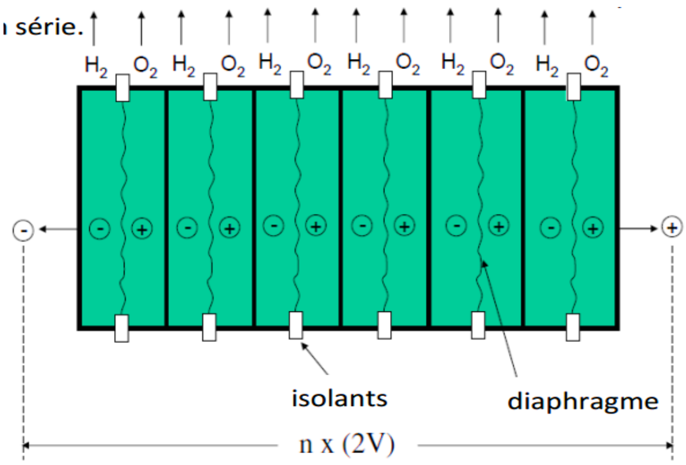
Bipolar

Diaphragm insulation

The bipolar systems, developed later on,

Role of anode on one side and cathode on the other, the electrolysis cells

Then function serially.



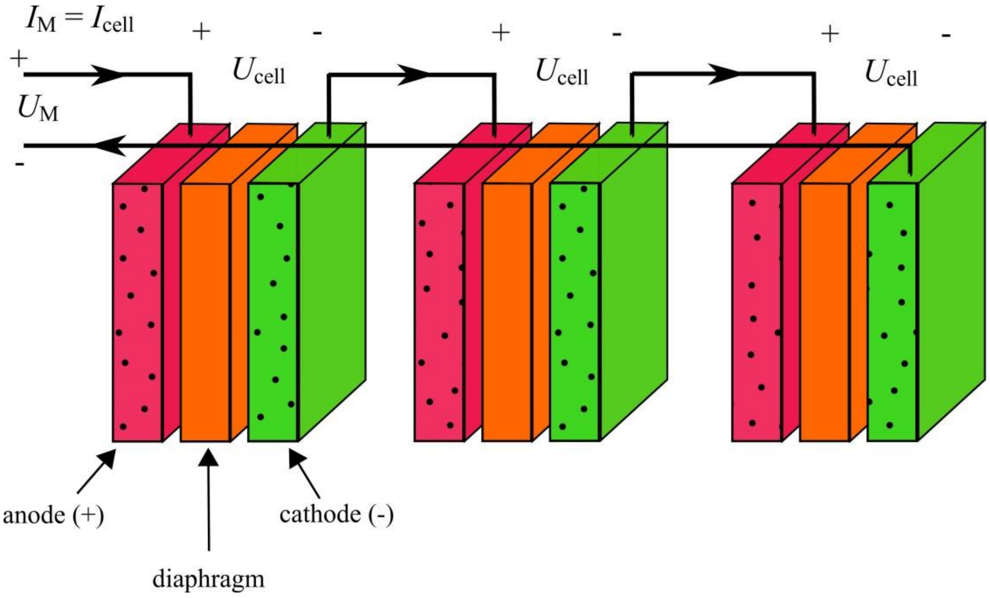


Figure 7:bipolaire

Monopolar		**Bipolar**
Advantages		
Simple and rugged design		Lower unit cell voltages
Relatively inexpensive parts		Higher current densities
Simple fabrication techniques		Intercell busbars greatly reduced
Few gasketed surfaces		Rectifier costs more easily optimized
Individual cells easily checked		Can readily operate at higher pressures and temperatures
Cells easily isolated for maintenance		Pressure operation eliminates

		compressors
No parasitic currents in system		Easier to control entire system for temperature and electrolyte level
Minimum disruption to production (say by, single cell failure) for maintenance problems		Fewer spare parts required
Cells easily maintained on site		Individual cell frames can be very thin, thus providing a large gas output from a small piece of equipment
No pumps or filters required		Fallout from military and aerospace programs in fuel cells as well as hydrogen oxygen production generation has greatly assisted bipolar cell development
Simple internal gas lift circulation		Mass production of plastic cell components could result in lower capital costs
		Potential to operate at very high current densities
		Electrical arrangements of electrolysers can allow a ground potential where the gases and electrolyte leave the system, or electrolyte enters the system
Disadvantages		
Difficult to achieve small interelectrode gaps		Sophisticated manufacturing and design techniques required
Heavy intercell busbars		Parasitic currents lower current efficiency
Inherently higher power consumption from potential drop in cell hardware		External pumping, filtration, cooling, and gas disengaging system required
Cell pressures and temperatures limited by mechanical design		Malfunction of a unit cell difficult to locate
Each cell requires operator attention for temperature, electrolyte level, and gas purity		Repair to a unit cell requires entire electrolyser to be dismantled (in practice)
Sludge and corrosion products collect within cell		Higher disruption to production for maintenance problems

Table 3:comparaison between mono and bipolar cells

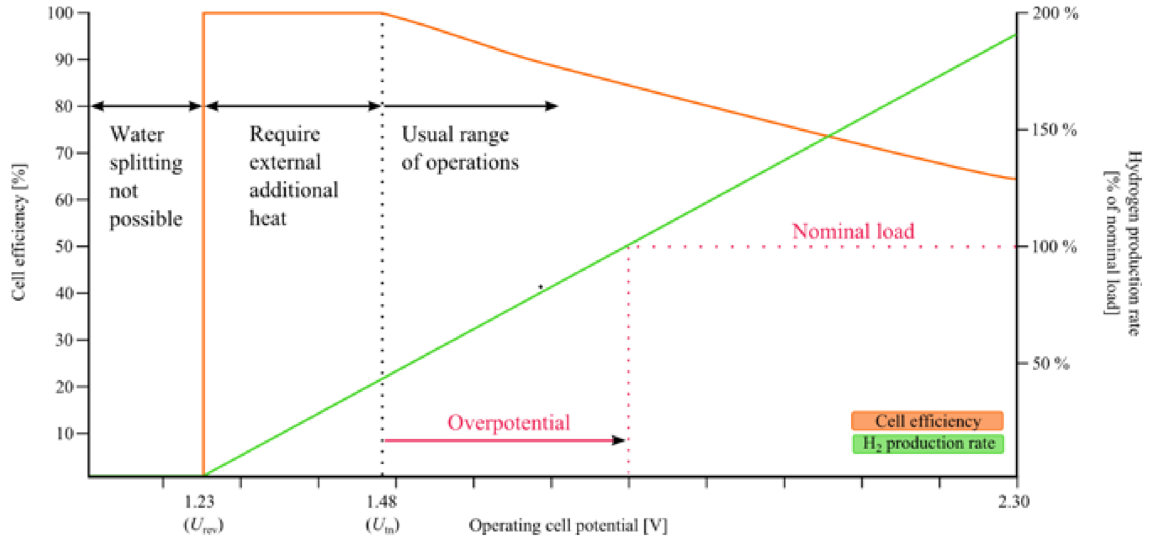


Figure 8: Illustrative cell efficiency and H_2 production rate as a function of cell voltage

For aqueous water electrolysis, the reversible voltage can be written as a function of temperature and pressure (LeRoy et al. 1980) as

$$U_{\mathrm{rev}}(T,p) = U_{\mathrm{rev}}(T) + \frac{RT}{zF}\ln\left[\frac{(p-p_{\mathrm{v}})^{1.5}p_{\mathrm{v}}^{*}}{p_{\mathrm{v}}}\right], \quad (2.5)$$

where R is the universal gas constant (8.3144621 J·mol^{-1}·K^{-1}), p_{v} the vapour pressure of the electrolyte solution (atm), and p_{v}^{*} the vapour pressure of purified water (atm). $U_{\mathrm{rev}}(T)$ can be expressed according to (LeRoy et al. 1980) and (Tilak et al. 1981) as follows

$$U_{\mathrm{rev}}(T) = 1.5184 - 1.5421\cdot 10^{-3}T + 9.523\cdot 10^{-5}T + 9.84\cdot 10^{-8}T, \quad (2.6)$$

where temperature is in degrees Kelvin. The effect of pressure on the reversible cell voltage—calculated using (2.5) and (2.6)—is illustrated in Fig.

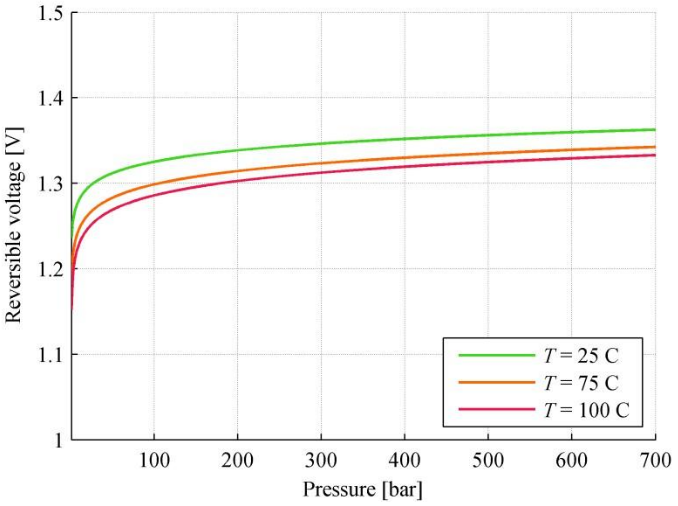
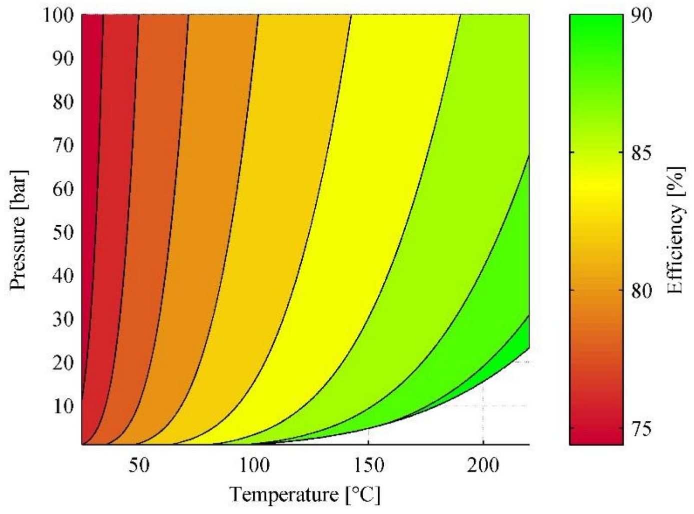
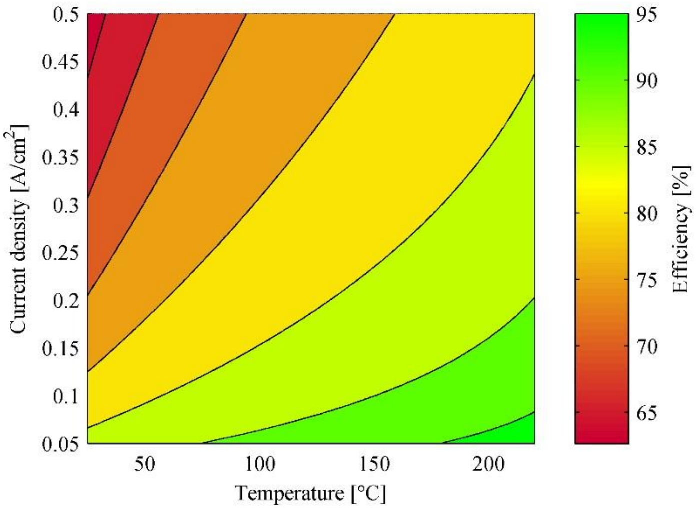


Figure 9: Reversible voltage as a function of pressure at temperatures T = 25 °C, T = 75 °C, and T = 100 °C in aqueous water electrolysis. Calculations are for 30 wt% KOH electrolyte which has an electrolyte molality of 7.64 mol/kg.

	Figure 10: Simulated alkaline electrolyser cell efficiency (HHV) with varying temperature and pressure with a constant current density i = 0.2 A/cm^2. Efficiency is not simulated at points where the prevailing pressure is lower than the vapour pressure of pure water.
	Figure 11: Simulated alkaline electrolyser cell efficiency with varying temperature and current density at constant pressure p = 30 bar.

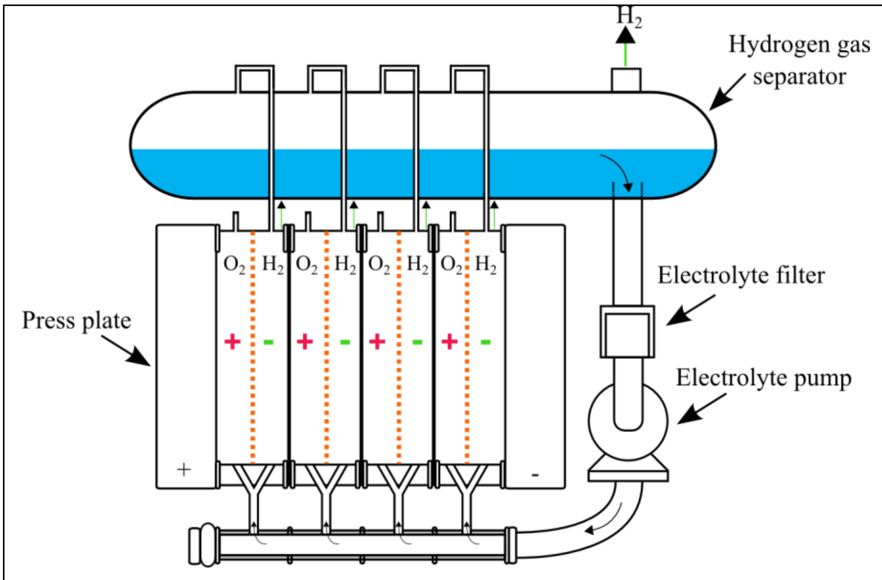


Figure 12: Overview of a typical alkaline electrolysis plant viewed from the hydrogen side. Product (wet) gases from the electrolyser stacks rise to the gas separator tanks where they are separated from the remaining electrolyte. Oxygen gas is treated in its own gas separator tank. Water is continuously added into the system to maintain the desired electrolyte concentration

Maturity	Commercial
Current density	0.2–0.4 A/cm^2
Cell area (1)	< 4 m^2
Hydrogen output pressure	0.05–30 bar
Operating temperature	60–80 °C
Min. load	20–40 % 5 % (state of the art) (2)
Overload (1)	< 150 %(nominal load)
Ramp-up from minimum load to full load	0.13–10 %(full load)/second
Start-up time from cold to minimum load	20 min – several hours
H_2 purity	99.5–99.9998 %
System efficiency (HHV) (2)	68–77 %
Indicative system cost	1.0–1.2 €/W
System size range	0.25–760 Nm^3/h 1.8–5300 kW
Lifetime stack	60 000–90 000 h

Table 4: 2 Alkaline electrolyser characteristics. Values collected from (Bertuccioli et al. 2014) except (1) from (Lehner et al. 2014) and (2) from (Decourt et al. 2014).

5.4 Pressurized operation

Water electrolysers can be categorized into atmospheric and pressurized electrolysers depending on the pressure level at which electrolysis takes place. An overview of these two categories is illustrated in Fig. below:

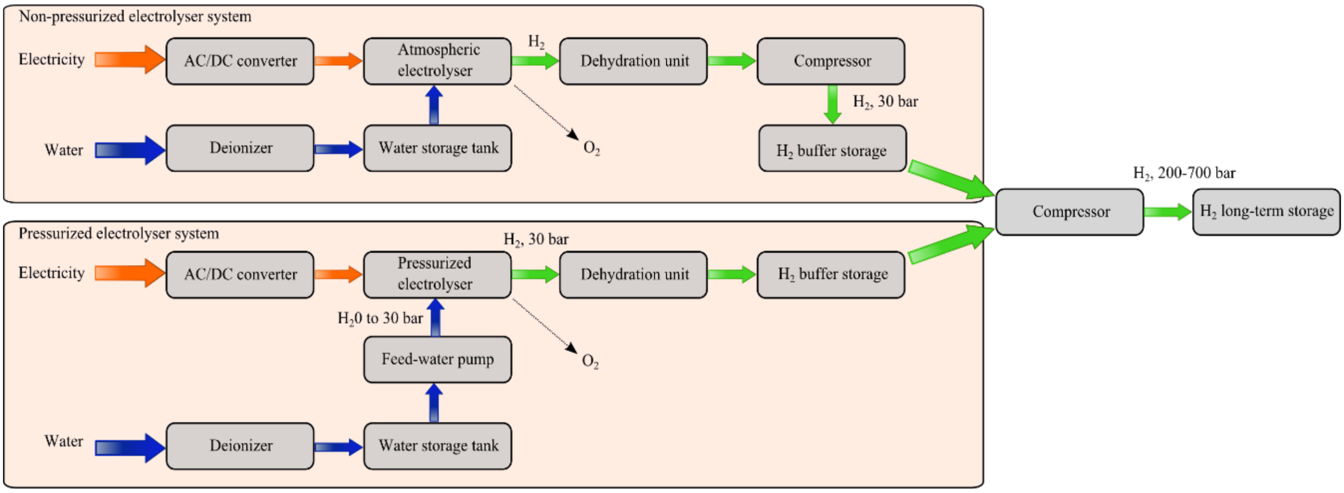


Figure 13: 10 Overview of exemplary non-pressurized and pressurized water electrolyser systems. Hydrogen buffer storages store hydrogen gas at around 10–30 bar. From the buffer storage, hydrogen gas may be further compressed to 200–700 bar. The highest pressure requirement is in mobility end-use applications, typically 350–800 bar.

5.5 Main features of commercially available electrolysers

Water electrolyzer systems have auxiliary equipment, which enable the automatic production of electrolytic hydrogen. Generally, water electrolyser systems comprise the following components and subsystems:

- power supply and power converter
- water deionizer (and a buffer tank for deionized water)
- water circulation pump
- gas purification unit
- gas storage
- control system
- ventilation system

Alkaline electrolysis systems need pumps and filters to continuously supply and distribute the liquid electrolyte. Water is consumed and has to be supplied to maintain the correct electrolyte concentration. One example of a small alkaline electrolysis system is illustrated in Fig 14.

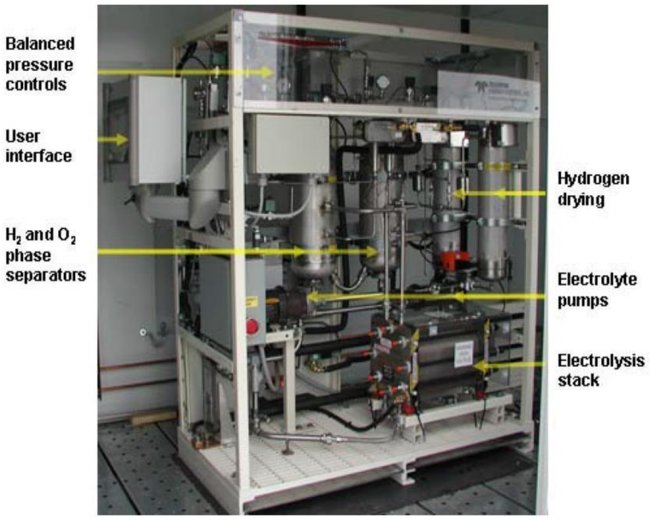


Figure 14: System components of Teledyne Energy Systems' 40 kW alkaline hydrogen generator (Harrison et al. 2009). Measurements of the enclosure are 150 x 178 x 75 cm.

5.6 Power electronic systems

A water electrolyser is a DC load and thus the input power for the electrolyser has to be either AC/DC or DC/DC conditioned. The control of the power conditioning stage enables the selection of suitable output power. Principle idea of power conditioning and control is described in Fig. 15

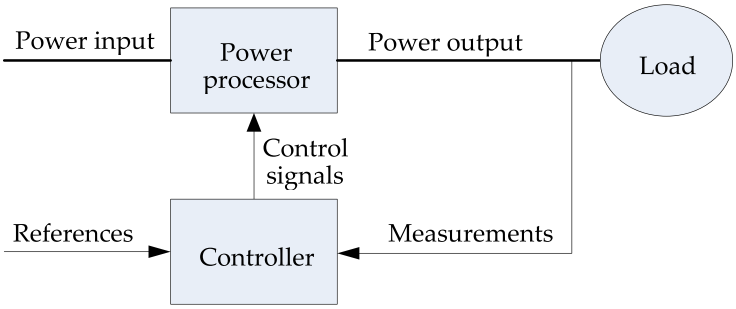


Figure 15: 3 General scheme of a power electronic system

5.7 Design of cells

5.7.1 PEM Electrolysis (Proton Exchange Membrane)

The acid electrolysis is distinguished from the previous one by a solid electrolyte with a proton-conducting polymer membrane (FIG. 4). The advantages of this technology are the absence of liquid electrolyte, compactness, simplicity of manufacture, simplicity of design and operation, limitation of corrosion problems, significantly higher performance and less influence of variation in conditions (Interesting for intermittent renewable sources). However, the cost of the polymer membrane and the use of electro-catalysts based on noble metals, lead to equipment nowadays more expensive than the alkaline electrolyzers of the same capacity. Polymer membrane electrolysis is considered by many to be a technology of the future as it benefits from the many developments on comparable technology (PEM) fuel cells and the associated cost reduction.

Small-capacity polymeric membrane electrolysis is already a mature technology that has been used for several decades for underwater applications (oxygen plants aboard US and British nuclear submarines) and space (For the generation of oxygen in the life compartments).

These units can operate from atmospheric pressure to several tens of bars, even a few hundred bars).

This type of electrolyser is particularly suitable for coupling to a renewable energy source because it supports the variations in available electrical power better than alkaline electrolysis. Moreover, in view of the better performance of available electrolyzers, this type of acid electrolysis has a better yield (5 to 10 points more) than that of alkaline electrolysis.

Standards and codes on the design and / or installation of small capacity electrolysers are being developed, in particular within ISO TC 197 dedicated to hydrogen technologies

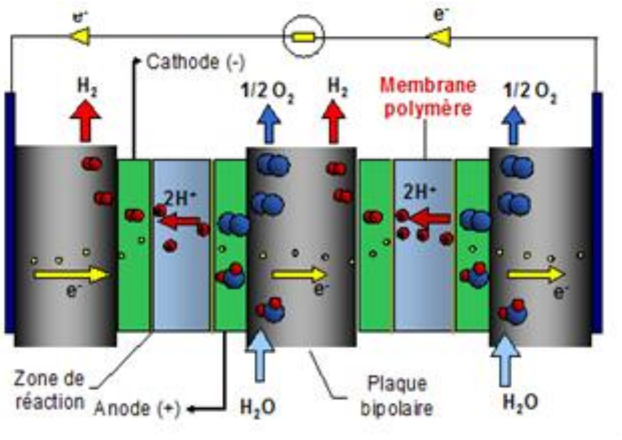


Figure 16: electrolyse pem

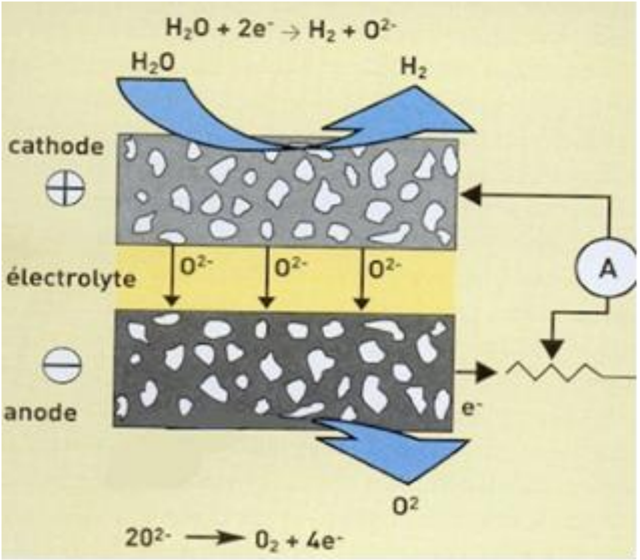
anode :$2 H_2O \Rightarrow O_2 + 4 H^+ + 4 e^-$

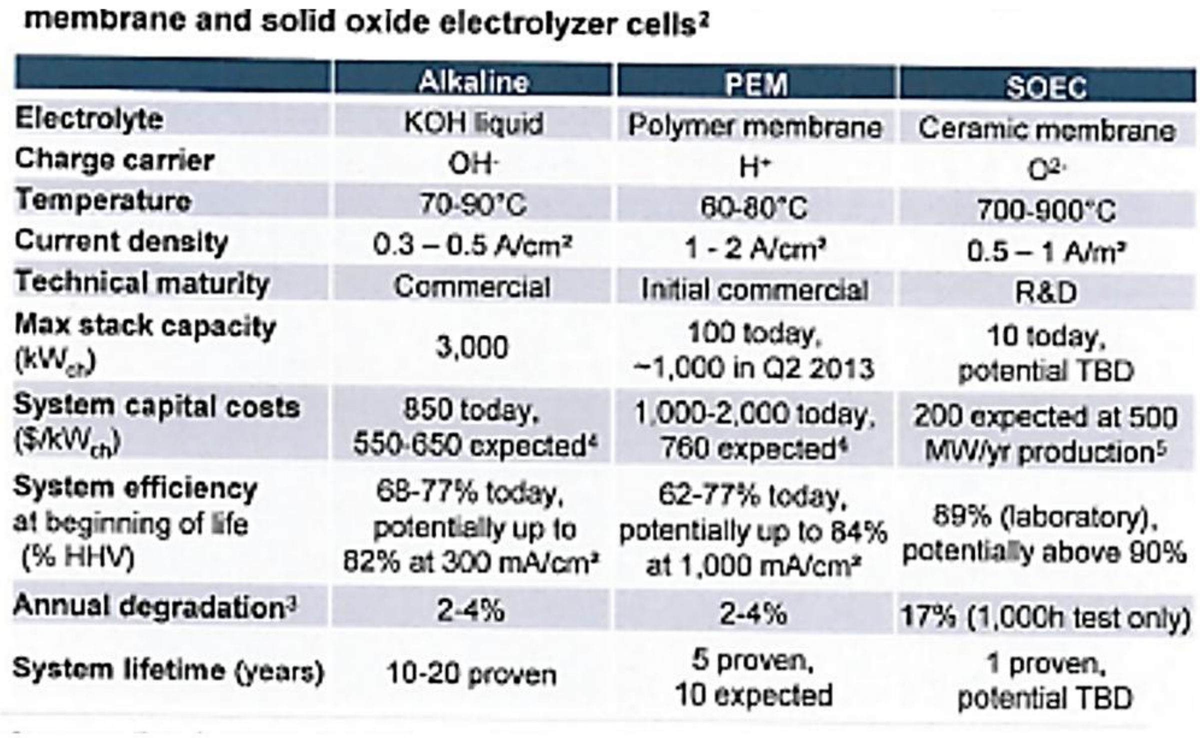
cathode :$2 H^+ + 2 e^- \Rightarrow H_2$

Figure 17: **Electrolyser PEM AREVA H_2GEN/CETH$_2$ 120 Nm^3/h (2015)**

5.7.2 High temperature electrolysis (PCFC or SOEC)

This technology is directly derived from developments in the PCFC or SOFC fuel cell (Figure 6), operating respectively in the 400 - 600 ° C and 650 - 1000 ° C ranges. It is advantageous if it is supplied with both electricity and heat in order to maintain the desired high temperature, the yield can then be greater than 80% if the heat of vaporization of the water is not taken into account. It is essentially intended to be coupled to a concentrated solar system or to a high temperature nuclear reactor. It is in the development stage in various laboratories such as CERAMATEC or Idaho National Engineering and Environmental Lab. In the USA and CEA in France, in particular through a start-up called Sylfen, which is developing a reversible SOFC (fuel cell electrolysis) technology.




membrane and solid oxide electrolyzer cells[2]

	Alkaline	PEM	SOEC
Electrolyte	KOH liquid	Polymer membrane	Ceramic membrane
Charge carrier	OH^-	H^+	O^{2-}
Temperature	70-90°C	60-80°C	700-900°C
Current density	0.3 – 0.5 A/cm^2	1 - 2 A/cm^2	0.5 – 1 A/m^2
Technical maturity	Commercial	Initial commercial	R&D
Max stack capacity (kW_{ch})	3,000	100 today, ~1,000 in Q2 2013	10 today, potential TBD
System capital costs ($\$/kW_{ch}$)	850 today, 550-650 expected[4]	1,000-2,000 today, 760 expected[4]	200 expected at 500 MW/yr production[5]
System efficiency at beginning of life (% HHV)	68-77% today, potentially up to 82% at 300 mA/cm^2	62-77% today, potentially up to 84% at 1,000 mA/cm^2	89% (laboratory), potentially above 90%
Annual degradation[3]	2-4%	2-4%	17% (1,000h test only)
System lifetime (years)	10-20 proven	5 proven, 10 expected	1 proven, potential TBD

Figure 18:differences between 3 types of electrolyzer

A microprocessor to control a electolyser **as trnsys**

6 خزان الهيدروجين (Reservoir for the conservation of HYDROGEN)

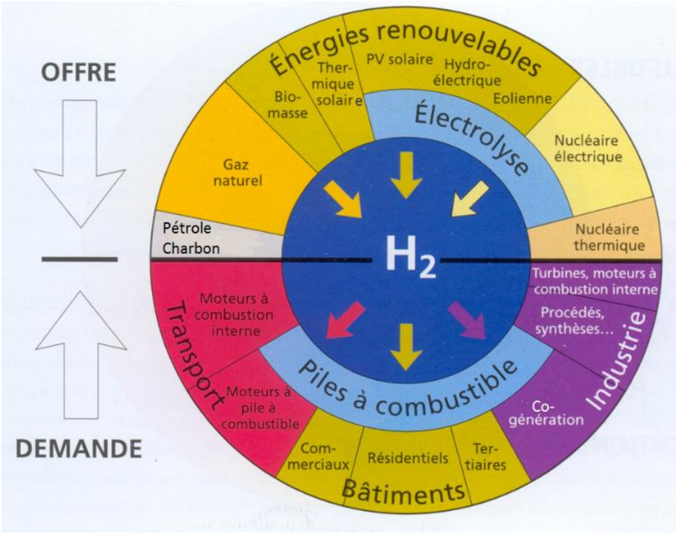


Figure 19: The hydrogen chain (documentaire)

Hydrogen is a very light gas that can be heavily compressed to reduce its mass volume. The simplest method of reducing the volume of a gas at constant temperature is to increase its pressure. Thus, at 700 bar, that is to say 700 times the atmospheric pressure, the hydrogen has a density of 42 kg / m3 compared with 0.090 kg / m3 at normal pressure and temperature. At this pressure, 5 kg of hydrogen can be stored in a 125-liter tank. Today, hydrogen is already distributed in steel cylinders in which it is stored at 200 bar. To further improve storage capacity, industrialists are developing composite cylinders or tanks, materials much lighter than steel, that store hydrogen to a pressure of 700 bar.

6.1 Hydrogen storage

Since the volumetric energy density of hydrogen is low, advantage should be taken of hydrogen's high energy density on a mass basis. The main ways to increase hydrogen's volumetric energy density and to store hydrogen are presented in Table 4.1.

Table 4.1 The six main hydrogen storage methods and the associated phenomena, where ρ_m is the gravimetric density and ρ_v the volumetric density (Züttel 2007).

Storage method	**ρ_m [mass%]**	**ρ_v [kg_{H2}/m^3]**	**T [°C]**	**p [bar]**	**Phenomena and remarks**
High pressure gas cylinders	13	< 40	25	800	Compressed gas (molecular H2) in light weight composite cylinder
Liquid hydrogen in cryogenic tanks	Size dep.	70.8	−252	1	Liquid hydrogen (molecular H2), continuous loss of a few % per day of hydrogen at room temperature
Absorbed on interstitial sites in a host metal	≈ 2	150	25	1	Hydrogen (atomic H) intercalation in host metals, metallic hydrides working at room temperature are fully

					reversible
Absorbed hydrogen	≈ 2	20	−80	100	Physisorption (molecular H2) on materials e.g. carbon with a very large specific surface area, fully reversible
Complex compounds	< 18	150	> 100	1	Complex compounds ([AlH4]- or [BH4]-), desorption at elevated temperature, adsorption at high pressures
Metals and complexes together with water	< 40	> 150	25	1	Chemical oxidation of metals with water and liberation of hydrogen, not directly reversible?

Table 5The six main hydrogen storage methods and the associated phenomena, where ρ_m is the gravimetric density and ρ_v the volumetric density (Züttel 2007).

Compression to pressurized tanks is currently the preferred option and hydrogen can be compressed using standard piston-type mechanical compressors (Züttel 2007). If the cycling rate of the storage is high, pressurized tanks are a suitable and cost-effective method in small- and medium-scale applications (Decourt et al. 2014). Large-scale storage of pressurized hydrogen in salt caverns could be a possibility.

The boiling point of hydrogen is −253 °C (ISO 2004). Therefore, a lot of energy is needed in hydrogen liquefaction and liquid storage. In small- to medium-scale storage of electrolytic hydrogen, liquefaction is an ill-suited option (Decourt et al. 2014). Additionally, to the energy requirement of the liquefaction, the continuous boil-off of hydrogen limits the possible applications for liquid hydrogen storage systems (Züttel 2007).

Hydrogen reacts at elevated temperature with many transition metals and their alloys to form metal hydrides, for example $LaNiH_6$. Metal hydrides enable a very high volumetric density and have been identified as an effective method to store hydrogen safely (Züttel 2007). The safety of a metal hydride storage of hydrogen is due to the strong binding of atomic hydrogen (H) in the metal hydrides. The absorption and desorption of hydrogen is controlled by heat exchange. However, Züttel (2007, p. 360) noted that exploring the properties of light weight metal hydrides is still a challenge. All the reversible hydrides close to ambient temperature and pressure consist of transition metals and therefore the gravimetric hydrogen density is limited. Alternatively, hydrogen could be stored in liquid hydrocarbons, such as methanol and ethanol, or gaseous hydrocarbons, such as methane.

Prevention of fire and explosion risks

• ATEX Directive 94/9/EC on equipment and protective systems intended for use in potentially explosive atmospheres • ATEX Directive 1999/92/EC on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres • ATEX Directive 2014/34/EU on the harmonisation of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres (applicable from 20.4.2016) • Seveso II (Directive 96/82/EC) on prevention of major accidents involving dangerous substances, to be overwritten by Seveso III (Directive 2012/18/EU) on 1.6.2015
Safety of pressure equipment
□ Directive 97/23/EC on the approximation of the laws of the Member States concerning pressure equipment
Safety of machinery
□ Machinery Directive 2006/42/EC
Electrical safety
• Low Voltage Directive 2006/95/EC • Electromagnetic Compatibility Directive EMC-D 2004/108/EC

Table 6: *Directives on the safety of hydrogen generators using water electrolysis process ((2))*

6.2 LIQUID HYDROGEN IN CRYOGENIC TANKS

6.2.1 HYDROGEN - WEIGHT AND VOLUME EQUIVALENTS

Weight of Liquid or Gas		**Volume of Liquid at Normal Boiling Point**		**Volume of Gas at 70°F (21°C) and 1 atm**	
lb	**kg**	**L**	**gal**	**cf**	**m³**
1.000	0.454	6.409	1.693	192.00	5.437
2.205	1.000	14.132	3.733	423.360	11.988
0.156	0.071	1.000	0.264	29.952	0.848
0.591	0.268	3.788	1.000	113.472	3.213
5.208	2.362	33.381	8.818	1000.00	28.317
0.184	0.083	1.179	0.312	35.328	1.000

Table 7: HYDROGEN - WEIGHT AND VOLUME EQUIVALENTS (http://www.airproducts.com/products/Gases/gas-facts/conversion-formulas/weight-and-volume-equivalents/hydrogen.aspx)

Hydrogen is a gas at standard temperature and pressure and is the most common element in the universe. However, free hydrogen is extremely rare on Earth because it evaporates so easily in space. Liquid hydrogen is most commonly used as a rocket fuel where it's burned with liquid oxygen and it also has applications in cryogenics as a coolant. Liquid hydrogen is also a useful means of storing and transporting hydrogen because it takes up less room than it does as a gas. Hydrogen gas can be liquefied by applying the correct combinations of pressure and cooling.

Identify the critical temperature for hydrogen as 33 degrees Kelvin. This is the maximum temperature at which hydrogen can be a liquid, no matter how great the pressure is. The process of liquefying hydrogen must therefore get it below 33 degrees Kelvin (−423.17 °F/−252.87°C).

Determine the critical pressure for hydrogen as about 13 atmospheres (atm). This is the minimum pressure needed to keep hydrogen a liquid at its critical temperature. These critical points provide the parameters for keeping hydrogen a liquid.

Examine the regenerative cooling process. This method pressurizes gas and allows it to expand. This allows the gas to take heat from its environment, thus cooling it. The gas is then passed through a heat exchanger, which cools the gas, thereby compressing it. This process is repeated until the gas cools enough to liquefy.

Apply the regenerative cooling process to liquefy hydrogen as first performed by James Dewar in 1898. Pressurize the hydrogen to 180 atm and pre-cool it with liquid nitrogen. Allow the hydrogen to expand through a valve that is also cooled by liquid nitrogen.

Repeat Step 4 until the hydrogen liquefies. Dewar's experiment yielded about 20 cubic centimeters (CCs) of liquid hydrogen, which was about 1 percent of the hydrogen in the experiment (5)

الهيدروجين هو غاز في درجة حرارة والضغط القياسيين وهو العنصر الأكثر شيوعا في الكون. ومع ذلك، الهيدروجين الحر هو نادرة للغاية على الأرض لأنه يتبخر بسهولة في الفضاء. ويستخدم الهيدروجين السائل الأكثر شيوعا باعتباره وقود الصواريخ حيث انها حرقه مع الأكسجين السائل، ولها أيضا تطبيقات في فيزياء درجات الحرارة المتدنية كمبرد. الهيدروجين السائل هو أيضا وسيلة مفيدة لتخزين ونقل الهيدروجين لأنه يأخذ مساحة أقل بكثير مما هي عليه كغاز. غاز الهيدروجين يمكن المسال عن طريق تطبيق تركيبات الصحيحة من الضغط والتبريد.

تحديد درجة الحرارة الحرجة لالهيدروجين إلى 33 درجة كلفن. هذا هو الحد الأقصى لدرجة الحرارة التي الهيدروجين يمكن أن يكون السائل، مهما تعاظمت الضغوط هو. ولذلك يجب أن عملية تسييل الهيدروجين الحصول عليها دون 33 درجة كلفن.

تحديد الضغط الحرج للهيدروجين كما حوالي 13 الاجواء (ATM). هذا هو الحد الأدنى من الضغط اللازم للحفاظ على الهيدروجين السائل في درجة الحرارة الحرجة. وتوفر هذه النقاط الحرجة المعلمات للحفاظ على الهيدروجين السائل.

دراسة عملية التبريد التجدد. هذه الطريقة يضغط الغاز ويسمح لها بالتوسع. وهذا يسمح للغاز لاتخاذ الحرارة من بيئتها، وبالتالي تبريده. ثم يتم تمرير الغاز من خلال مبادل حراري، الذي يبرد الغاز، وبالتالي ضغط عليه. وتتكرر هذه العملية حتى يبرد ما يكفي من الغاز لتسييل.

تطبيق عملية التبريد التجدد لتسييل الهيدروجين كما يؤديها لأول مرة من قبل جيمس ديوار في عام 1898. ضغط الهيدروجين إلى 180 ضغط جوي وقبل تبريده مع النيتروجين السائل. السماح للهيدروجين لتوسيع من خلال صمام أن يتم تبريده أيضا النيتروجين السائل.

كرر الخطوة 4 حتى يسيل الهيدروجين. أسفرت التجربة ديوار حوالي 20 سم مكعب (CCS) من الهيدروجين السائل، الذي كان حوالي 1٪ من الهيدروجين في التجربة.

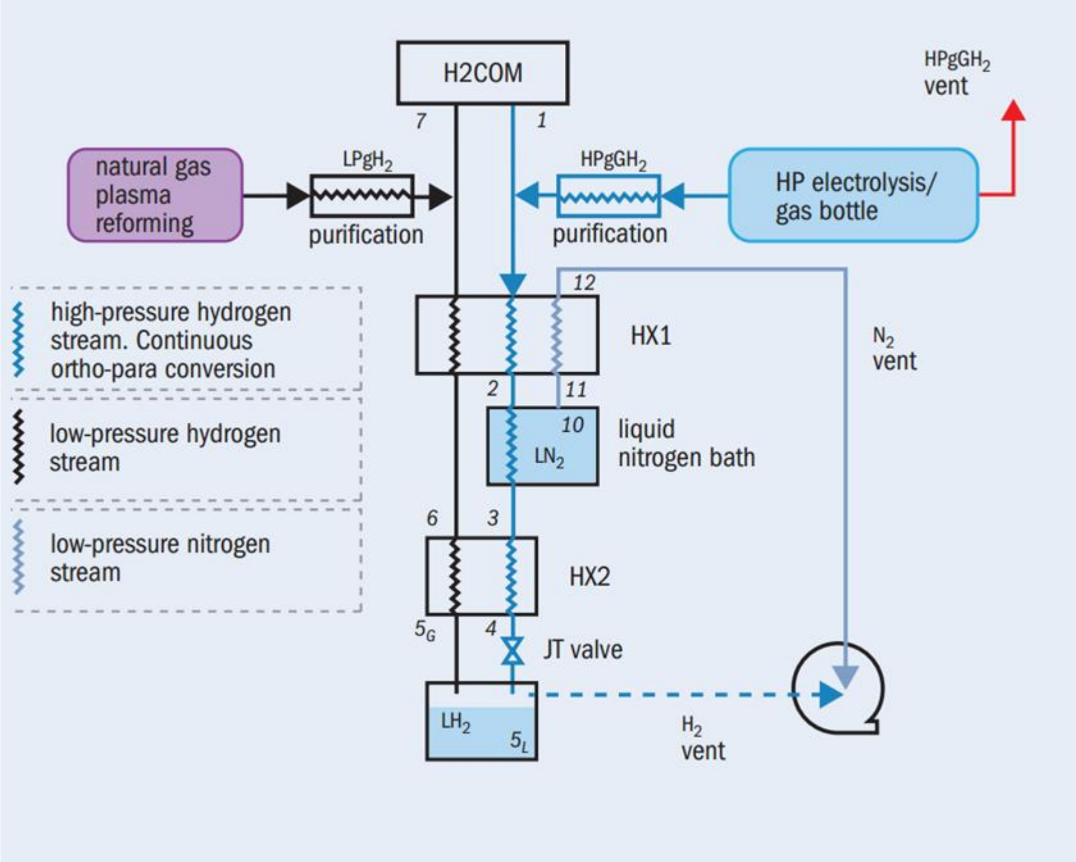


Figure 20: Schematic of the proposed pre-cooled Linde-Hampson system for hydrogen liquefaction. Ortho-para hydrogen conversiontakes place in a HX1 and HX2 zone

وقد تم تطوير نظام الهيدروجين تسييل من قبل ينده-هامبسون ويرد تخطيطي في الشكل أدناه.

يدخل الهيدروجين النقي دورة في النقطة (1) ويتم ضغط في النقطة 2 من ضاغط الهيدروجين (H2COM). فيHX1، البرد الغازات (النيتروجين والهيليوم) جنبا إلى جنب مع الهيدروجين عودة الباردة قبل تبريد تيار الهيدروجين الضغط العالي قبل أن يدخل

الحمام السائل النيتروجين. هذا الحمام يزيل الحرارة من الهيدروجين ويبرد عليه إلى درجة حرارة متوسطة في

نقطة 3. مضغوط تيار الهيدروجين تبرد قبل ثم يتدفق عبر الهيدروجين والهيدروجين مبادل حراريHX2

متصلا عودة تيار H2 البارد. وبهذه الطريقة، يتم تقليل تيار مضغوط في النقطة 4 إلى درجة الحرارة النهائية.

وأخيرا، يتم توسيع تيار الضغط العالي من خلال صمام جول طومسون الى الضغط تخزين) تصل إلى نقطة G)5

ودرجة الحرارة من K. 20في هذه المرحلة، والهيدروجين في حالة من مرحلتين ويتم إعادة تدوير الطور الغازي من خلال الحرارة

HX2المبادلات و HX1لإعادة ضغط. سوف ينتج عن ذلك من العائد السائل والهيدروجين من هذا النظام تختلف في حدود

15-7٪ اعتمادا على الضغوط الأولية والنهائية. درجة حرارة الهيدروجين النهائية قبل التوسع هو متغير رئيسي ل

الأمثل.

وميزة استخدام حمام التبريد هي أن تسمح لأكبر كمية من الطاقة لإزالتها من دفق الإدخال الهيدروجين في

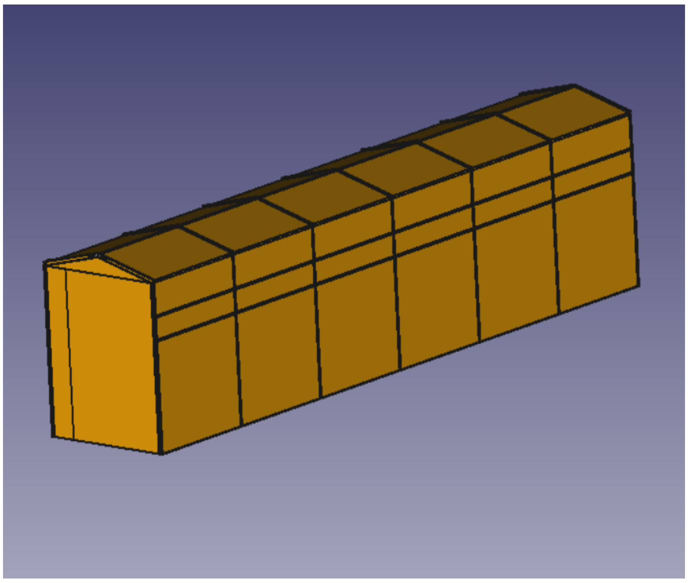
ارتفاع درجات الحرارة. وهذا يزيد من الكفاءة العامة للدورة. ميزة إضافية في هذا النظام هو التأسيس

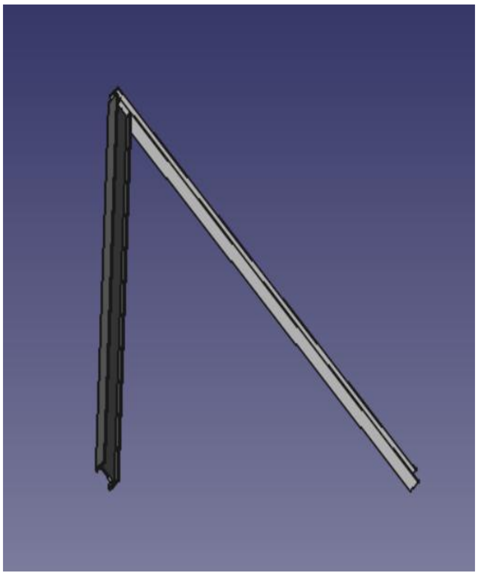
من حافزا أورثو-بارا في الممرات الداخلية للتيار الهيدروجين فيHX1 ، LN2و .HX2هذا حافزا يسمح للحرارة

تحويل إلى إزالتها بشكل مستمر وأكثر كفاءة. لضغوط تيار المدخلات الهيدروجين متفاوتة في المنطقة من 50

إلى 100 بار، سوف تختلف الضغط المنخفض تيار الهيدروجين معدلات التدفق الجماعي عودة 0.10 جم / ثانية إلى 0.17 غ / ل

7 هنغار (Hangar)





Length:24 m

Height : 5 m

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