# Analysis of Possibilities for Involvement of H2C Technologies and RE-Components in Heat Generation Industrial Systems

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# Analysis of Possibilities for Involvement of H2C Technologies and RE-Components in Heat Generation Industrial Systems

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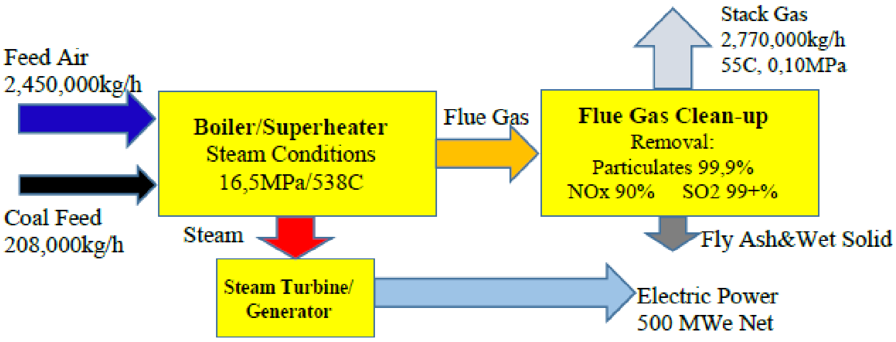
**Abstract**. The experience of technologically developed countries in solving the problems of improving the operational efficiency and environmental sustainability of coal-fired power generation of the Republic of Kazakhstan by involving H2C-technology and RE-components is summarized. It is shown that the successful example of technologically developed countries allows to use them as a transfer for energy systems of industrial heat generation in Kazakhstan.

## 1. Introduction

One of the main tasks in the energy industry is to continuously and continuously improve the energy efficiency of industrial coal-fired thermal generation systems (HGIS) [1]. One of the tools to improve the energy efficiency of these energy generating facilities are innovations based on the use of "hydrogen-carbon" (H2C) technologies [2,3] and RE components, which are required throughout the technological cycle: production, transmission-distribution, conversion-storage and energy consumption.

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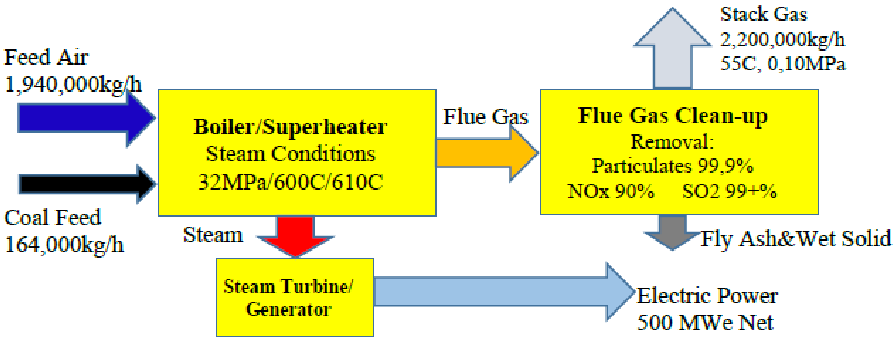



(B)

**Figure 1.** Conventional subcritical (A) and ultra-supercritical (B) process for a 500MW unit (CFPB) with pulverized coal fuel without carbon dioxide capture.

At the calculated degree of purification of combustion products emitted into the atmosphere (from solid particles - 99.9%; from nitrogen oxides - 90.0% and volatile sulfur compounds - 99.0% and more) emissions of gaseous combustion products (in which a significant proportion is carbon dioxide - CO2) make according to [1]: 2,770,000 kg/h for subcritical process CFPB and 2,200,000 kg/h for ultra-supercritical process CFPB generating electric power. Annual atmospheric emissions from the 500MW net power CFPB alone are at least 19,272,000 tons.

HGIS are in operation in the Pavlodar region of Kazakhstan: 10 CFPB-500 MW Ekibastuz SDPP-1 and SDPP-2. In addition, Aksu SDPP is also in operation, as well as several CHPP-type plants. Even without touching the peculiarities of CFPB operating modes, the high degree of wear of power equipment, the use of Ekibastuz field steam coal with high ash content, as well as the lack of operational efficiency of flue gas cleaning systems, we can assume that the actual amount of emissions will be not less than that shown in [1]. That is, "optimistic" (with well-functioning plant filters) annual atmospheric emissions only from GRES with CFPB 500MW will be more than 200 million tons. In Kazakhstan, more than 80% of the energy capacity is coal-fired. And this requires increased attention to minimizing environmental consequences for Pavlodar and East Kazakhstan regions. Emissions from CPS in Kazakhstan are about 1,600.0 grams for every kilowatt hour of electricity generated, which is a critical aspect for modernizing HGIS. There are several options for reducing CO2 emissions: 1) Reducing global energy intensity; 2) Expanding the use of renewable energy sources (RE); 3) Switching to less carbon-intensive fuels.

## 2. Introduction to Carbon Capture and Storage (CCS)

It can also be used in other industries: iron and steel, cement, synthetic fuel and ammonia production, biomass combustion, oil refineries, natural gas processing plants, etc. Post-combustion CO2 capture has been practiced for over 80 years; another option is to capture CO2 during combustion (before combustion); a third option is to replace combustion air with pure O2 mixed with recirculated flue gases [4-6]. This concept is commonly referred to as oxyfuel combustion; it produces a flue gas consisting only of CO2 and H2O. It is also possible to capture CO2 in various industrial processes, such as Figure 2.

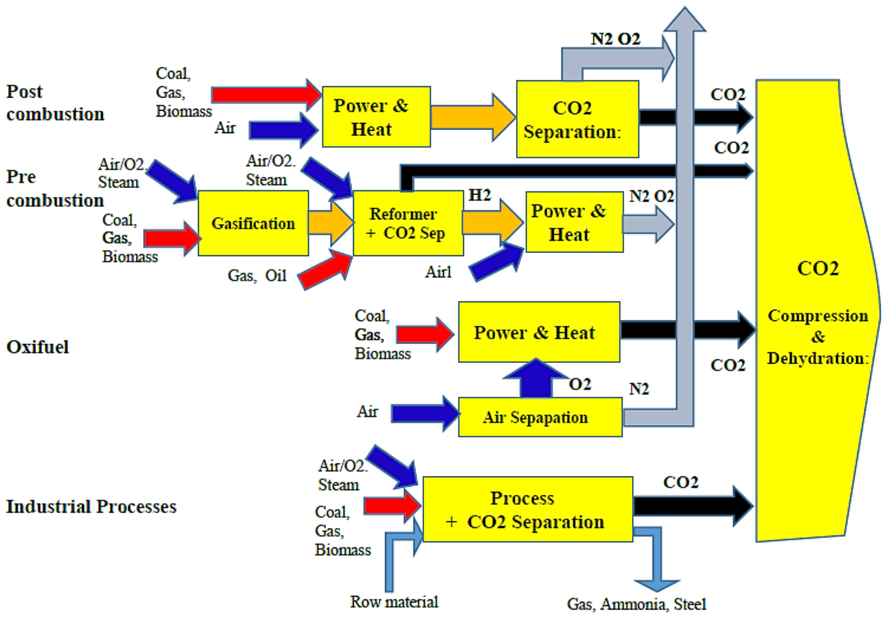
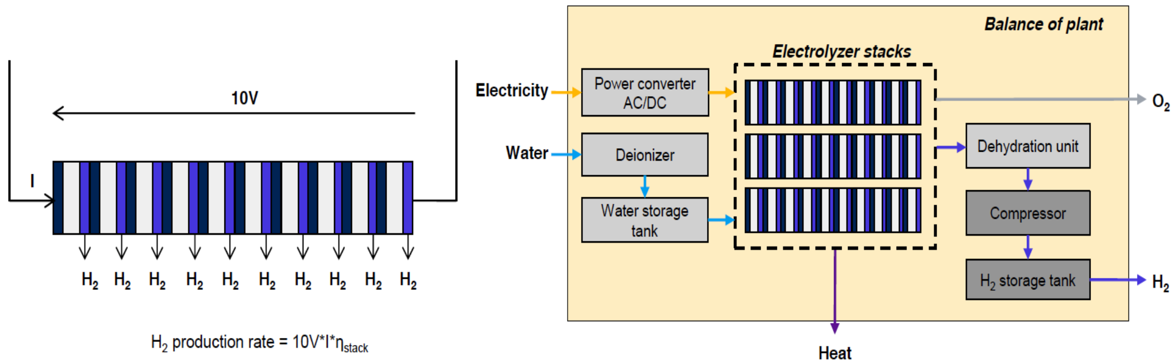



**Figure 2.** Opportunities of energy CCS-technologies.

Using hydrogen (H2) as a carbon-free energy carrier [2,3]. If fossil fuels are converted into H2 and the resulting CO2 is sequestered, an energy carrier is produced that can be fully utilized. H2 is a versatile energy carrier; it can be transported and stored; H2 can be used as a fuel in both gas turbines and FC. This makes it particularly suitable for promising HGIS retrofit projects with RE. The main methods for producing H2 are electrolysis: alkaline, proton exchange membrane (PEM), and solid oxide electrolysis cell (SOEC). Alkaline is the most common option; PEM is highly flexible; SOEC can be used in electrolysers or FC, up to 100 MW. H2 electrolysis technologies are shown in Figure 3.



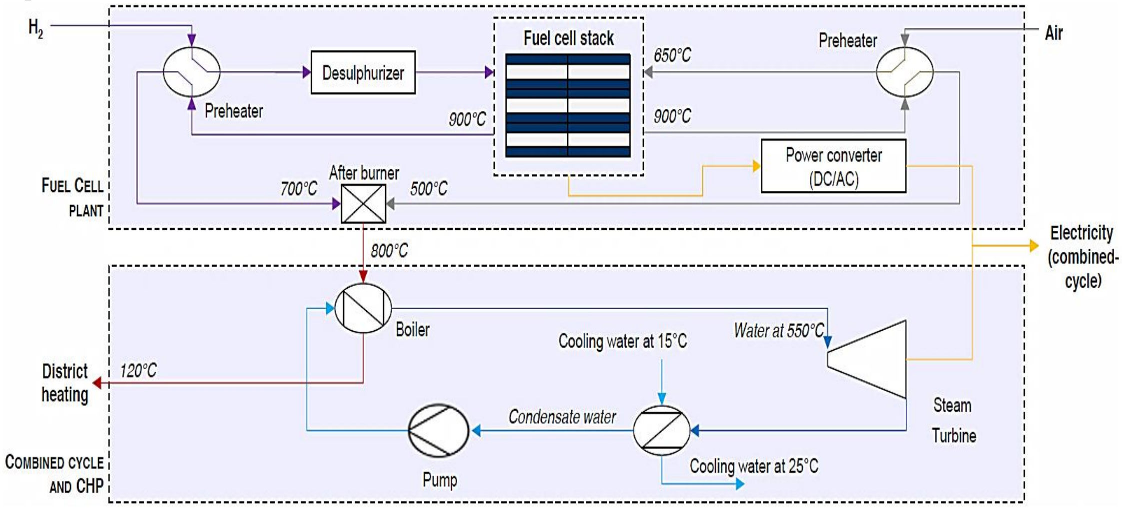

(A)

(B)

**Figure 3**. Schematic diagram of the process of obtaining H2 by electrolysis of fresh water; scheme (A) of the electrolyzer stack (left) and functional diagram of industrial H2 production (right); process diagram (B) industrial sample of alkaline H2 electrolyzer stack of 2.7MW(ch) [2,3].

## 3. H2-fueled power generation technologies [2,3]

Different types of FC [10-12] form the LTFC and HTFC categories. HTFCs (SOFCs) are more efficient for megawatt scale; commercially available; can be operated using H2, syngas, methane, or methanol. Gas turbines can be used to burn pure H2 or its gas mixture. Hydrogen-to-electricity efficiencies are: about 30% for LTFC; 45% for H2 turbines operating in an open cycle; 50% for HTFC (SOFC) and up to 60% for H2 turbines operating in a combined cycle [13], with the potential to increase to 80%. Combining power generation with district heating creates a cogeneration (2G) system [13,14] for which both LTFC and HTFC are suitable. Large scale HTFC or H2 turbines will be the most suitable systems for combined cycle plants [13,14].

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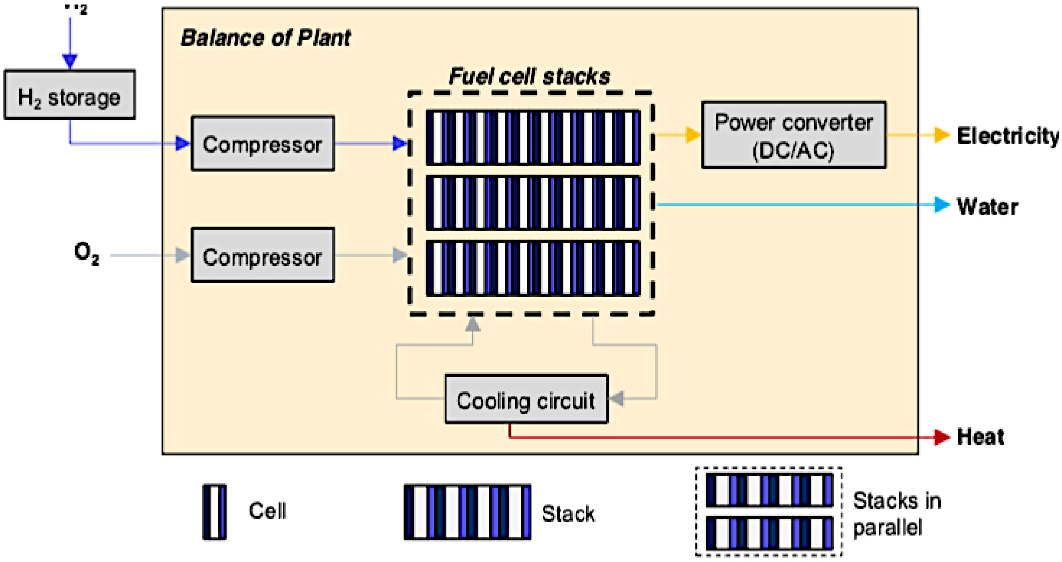



(B)

**Figure 4.** Process diagram of SOFC-stack generating station with cogeneration and combined cycle (A); diagram of H2FC-based industrial heat, electricity and clean fresh water generation station (B) [13,14].

The FC plant consists of FC stacks connected in series, plus the balance of the plant consisting of pumps, compressors, power converters, cooling circuits and other small components [10-12]. As with electrolysis, LTFCs include alkaline fuel cells (AFCs) and proton exchange membrane fuel cells (PEMFCs). PEMFCs are considered more promising. HTFCs include: phosphoric acid - PAFC, molten carbonate fuel cells - MCFC and solid oxide fuel cells - SOFC; the latter operate at high temperatures and are suitable for stationary 2G plants.

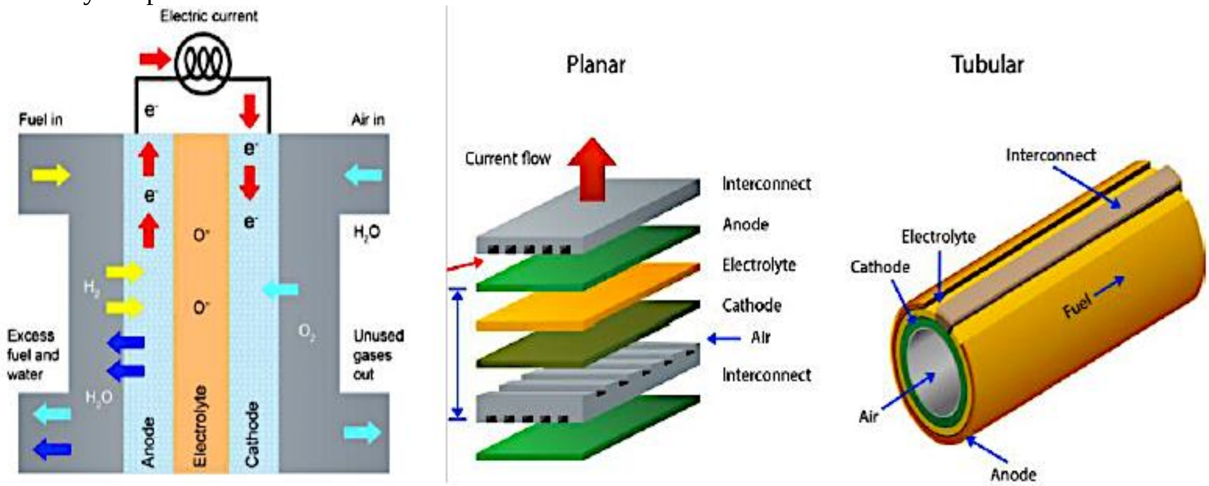
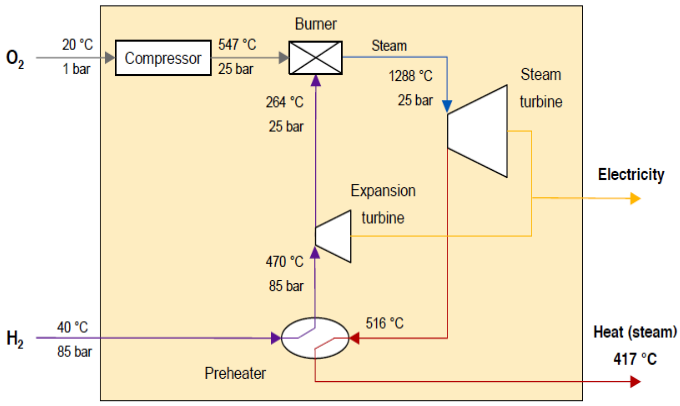



**Figure 5.** SOFC process flow diagram and basic design layouts [10-12].

Gas-fired flexible fuel and H2-turbines and RE-components for 2G-energy technology. Gas turbines can be a good alternative to fuel cells for large-scale stationary applications. Figure 6 shows a flow diagram of the 2G-energy generation process with hydrogen combustion technology. The H2-turbine contains a compressor, injector and combustion chamber; similar to a gas turbine. Advantages: almost zero greenhouse gas emissions; higher efficiency than conventional gas turbines; higher efficiency than FC in the combined cycle; low capital cost. Figure 6(B) shows a functional diagram of the prospective HCIS modernization using the example of the existing CPS with the involvement of H2C technologies. The HCIS, using the example of the existing CPS (marked black), is additionally equipped with: electrolysis systems to obtain H2 from water; systems of feeding into the technological process and industrial storage of alternative additional fuel - natural gas (marked red); additional energy sources based on RE-technology - PV, wind and others (marked yellow). In addition, the existing and introduced additional technological thermal and electrical equipment (indicated in gray).

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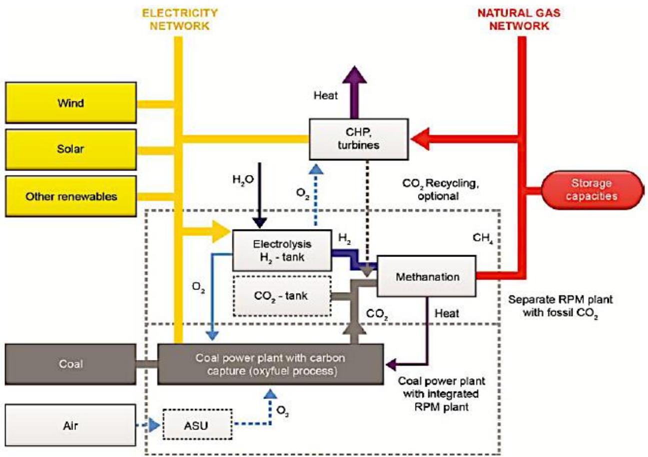


(B)

**Figure 6.** Process flow diagram (A) of 2G-energy production of H2 and steam turbine using hydrogen combustion technology; functional diagram (B) of innovative HCIS using H2S technology and RE.

Figure 7 shows coal fuel usage patterns for DCFC-type generating plants. Figure 7(A) shows a diagram of the use of coal fuel at CPS. This technology carries out one of the possible variants of H2C-technology, namely, the direct conversion of carbon into electrical energy. In addition, HE and clean water will be as "by-products" of the energy products. One possible variant of the H2C technology is shown in Figure 7(B).

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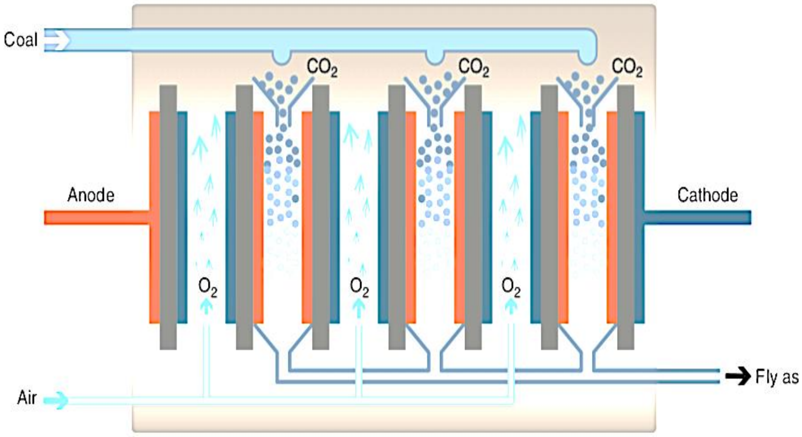
The primary fuel is pulverized coal, and small and inexpensive modules can be used to produce significant power generation capacity for electricity, HE (heating and cooling), and clean water.

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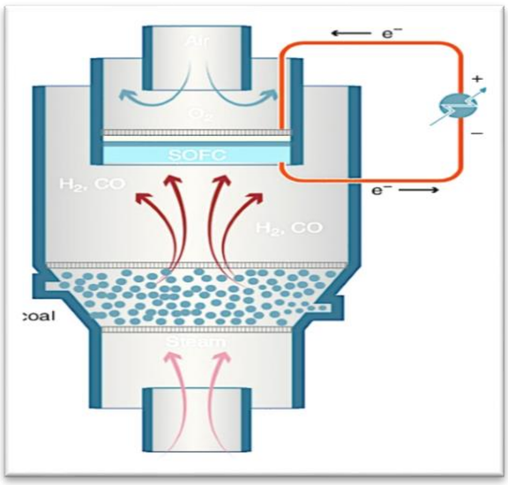


(B)

**Figure 7.** Schematic (A) of a coal DCFC system design for stationary generation at Innovative CPS with direct use of pulverized coal in FC; option (B) of a possible configuration for direct coal gasification and SOFC system with direct use of H2 and carbon monoxide in FC.

## 4. Trigeneration systems with FC elements to involve H2C technologies

Trigeneration **(**3G) systems include the processes of production and use of HE, electricity and refrigeration from a single fuel source [10-12,15-18]. This allows to obtain a higher level of energy efficiency, reduce emissions, increase the reliability of energy supply and contribute to the reduction of specific investments. 3G implementation area: FC, microturbines, Stirling engines, small wind turbines and PV. One of the technologies with the best opportunities for 3G system integration, is FC. The modular design, low noise and low emissions, flexible operation and high efficiency mean that these devices are very versatile. We distinguish the FC technologies: HTFC type MCFC and SOFC with temperatures ranging from 60°C to

1050°C and LTFC type PEMFC, DMFC, AFC, PAFC, with temperatures ranging from 60°C to 250°C. The combined use of electricity and HE gives an efficiency of about 85%. After the FC own needs are fully supplied, the remaining HE can be used to create steam or hot water in a 2G heat recovery boiler. In these HTFCs, additional power generation can be created with gas microturbines.

Absorption cooling systems for 3G energy systems can use any type of waste HE, steam, hot liquid or hot gas, providing cooling for air conditioning or for LT processes. They can be activated by residual flows of (60...80)°C and low pressure steam.

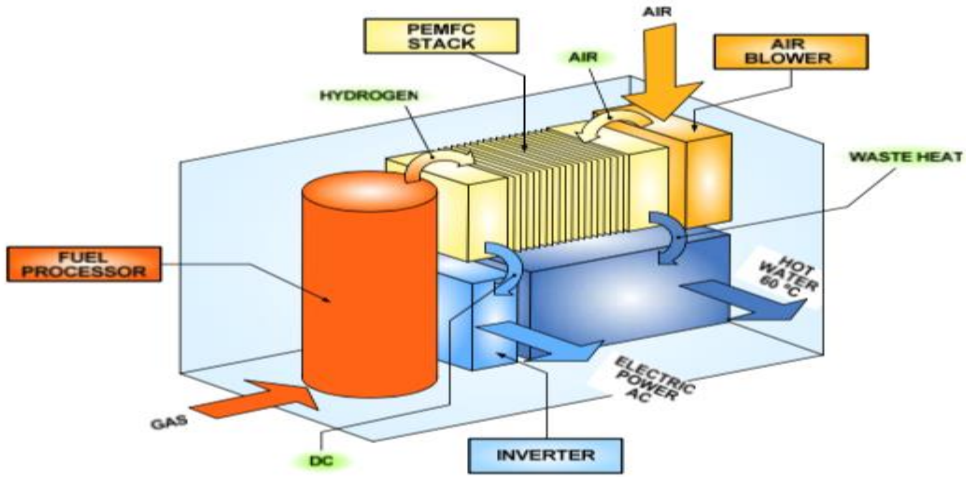


**Figure 8.** Modular layout of PEMFC system.

The HE used for refrigeration generation can be considered useful under the following conditions: for air conditioning (5...7) °C; any HE used in simple acting machines (up to 120°C); any HE used in double acting machines (up to 180°C); in industrial refrigeration production, any HE used in absorption machines (up to -50°C) is useful for cooling (up to 180°C). As an example, Figure 8 shows various FC PEM subsystems; the residual HE allows hot water (about 80°C), which is sufficient to run absorption cooling cycles [15]. Figure 9 shows the 3G FC systems. Achieved 3GFC technology: electrical efficiency - 43.3%; thermal efficiency: for heating - 43.7%, for cooling - 52.6%, for hot water production - 46.7%. Efficiency in three operating modes - up to 87.95%, 95.9% and 90%.

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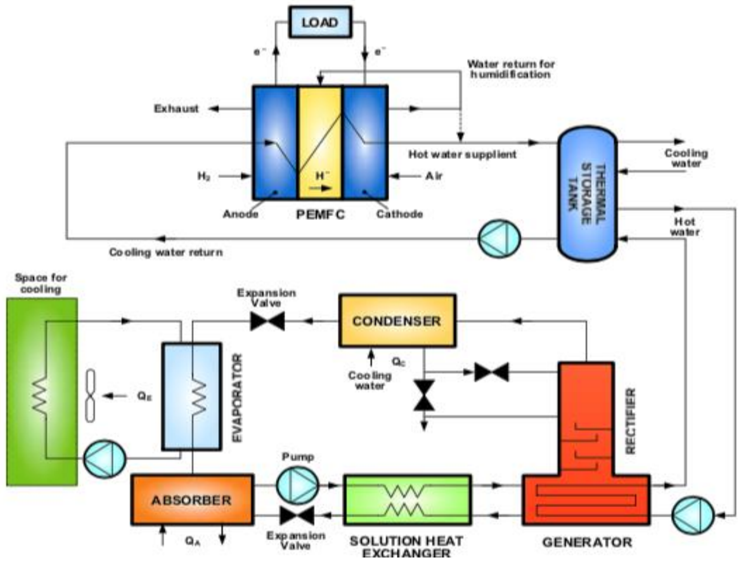


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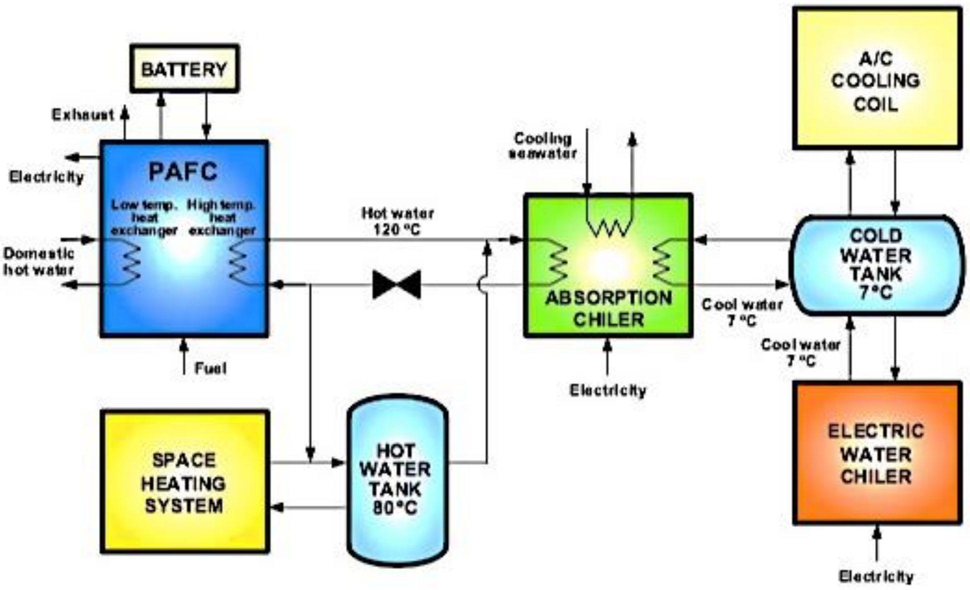


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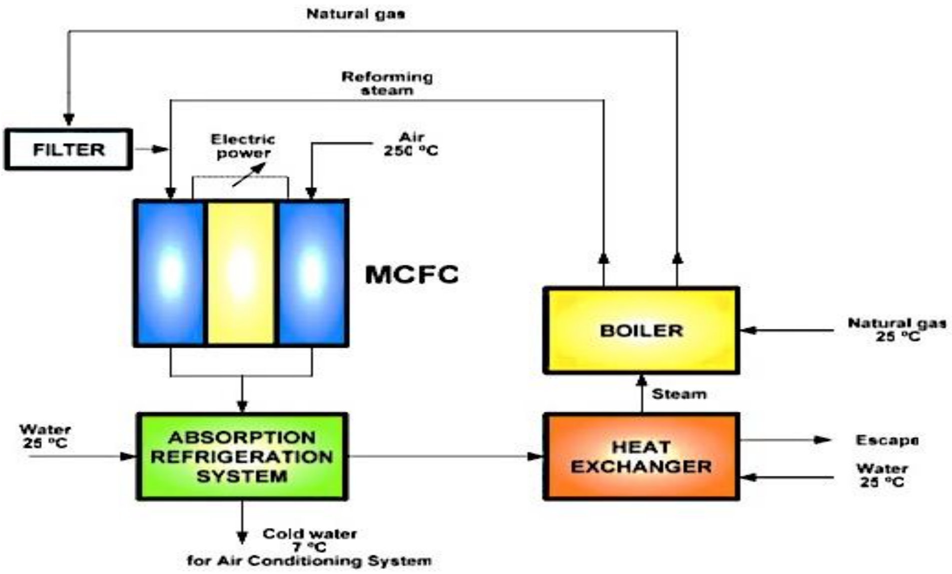


(C)

**Figure 9.** Schematic diagram (A) of 3G PEMFC technology; functional diagram (B) PAFC process air cooling system; MCFC system (C) chilled water generation.

## 5. Conclusion

Of particular interest are systems capable of using residual heat sources of industrial origin or in 2G installations: HT systems (300...700)°C with HTFC (PEMFC, PAFC, MCFC or SOFC) are suitable for constant power operation, while LTFC (up to 100°C) are more suitable for variable power operation.

**References:**

[1] MIT (Massachusetts Institute of Technology), The Future of Coal in a Carbon Constrained World, http://mit.edu/coal 2007
[2] Bolat P and Thiel C 2014 *Int. J. Hydrogen Energy* **39** 8881–97
[3] Bolat P and Thiel C 2014 *Int. J. Hydrogen Energy* **39** 8898–925
[4] Burchell T D, Judkins R R and Wilson K A 2002 *Device for separating CO2 from fossil-fueled power plant emissions* (US Patent 6,357,716)
[5] Ho M Y, Allinson G W and Wiley D E 2008 *Ind. Eng. Chem. Res* **47**(14) 4883
[6] Knudsen J N, Jensen J N, Vilhelmsen P-J and Biede O 2009 *IOP Conf. Ser. Earth Environ. Sci.* **6** 172002
[7] Hasan M M F 2017 *Multi-scale Process Systems Engineering for Carbon Capture, Utilization, and Storage. In Process Systems and Materials for CO2 Capture* ed Papadopoulos A I and Seferlis P (Hoboken: John Wiley & Sons Ltd)
[8] Field R P, Brasington R 2011 *Ind. Eng. Chem. Res.* **50** 11306–12
[9] Adams T A, Hoseinzade L, Madabhushi P B and Okeke I J 2017 *Processes* **5** 44
[10] Tucker D, Shelton M and Manivannan A 2009 *Electrochem. Soc. Interface* **18** 45
[11] Zink F, Lu Y and Schaefer L 2007 *Energy Convers. Manag.* **48**(3) 809–18
[12] Darwish M A 2007 *Appl. Therm. Eng.* **27** 2869–76
[13] Borelli D, Devia F, Schenone C and Spoladore A 2015 *Energy Procedia* **81** 505–15
[14] Adams T A, Barton P I 2011 *Fuel Process. Technol.* **92** 2105–15
[15] Roqueta J M and Márquez M 2007 *Trigeneration: The heat useful in the production of cold*

[16] Meerman J C, Ramírez A, Turkenburg W C and Faaij A P C 2011 *Renew. Sustain. Energy Rev.* **15** 2563–87
[17] Adams T A, Ghouse J H 2015 *Curr. Opin. Chem. Eng* **10** 87–93
[18] Jana K, Ray A, Majoumerd M M, Assadi M and De S 2017 *Appl. Energy* **202** 88–111