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THE ROLE OF TURBOMACHINERY IN THE TRANSITION TO A LOW CARBON SOCIETY

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Abstract

The oil and gas industry has been historically the platform for the development of rotating machinery technology. The world is now starting a paradigm shift towards a society less dependent on fossil fuels, given the intense pressure for the de-carbonization of the energy, transport and industrial sectors. The turbomachinery industry shall pay careful attention to the new challenges and opportunities that are already showing up. Among the significant challenges for renewable energy such as solar and wind, intermittency and storage are addressed with different approaches and the integration of gas-fired power is a promising opportunity. This paper gives an overview of the main trends that will affect the turbomachinery technology, including design, new applications, and hybridization.

1. Introduction

The world is experiencing the beginning of new era towards a low carbon society, given the intense pressure for the de-carbonization of the energy, transport and industrial sectors. Despite controversies and skepticisms, the transition has already started. Many experts have now agreed that the oil industry will no longer survive beyond 2050, at least not as a primary energy provider, but as a secondary petrochemical products supplier instead. As the Stone Age did not end due to the lack of stones, the fossil era will not finish due to the shortage of oil.

The turbomachinery industry is about to face new challenges and opportunities. Among the significant challenges for renewable energy such as solar and wind, intermittency and storage are addressed with different methods and the integration of gas-fired power is a promising opportunity. On the other hand, concentrated solar power has been developed considering both conventional steam cycles and innovative direct heating turbomachinery and supercritical CO_2 power cycle. The Supercritical CO_2 technology and its spillover effects will also challenge the turbomachinery industry. It is a technology that is expected to be mature enough by the middle of the next decade, prompting innovative solutions that will benefit natural gas (Allam Cycle), renewables, and the 4th generation of nuclear reactors.

The carbon capture and sequestration (CCS) technologies under development are facing major cost issues. However, it shall not be neglected as the way to postpone the life of coal-fired plants and other industrial applications, given the growing number of countries that are adopting carbon-pricing mechanisms.

This article aims to explore these challenges providing an overview of the main trends that will affect the turbomachinery technology, including design, new applications, and hybridization.

2. Market Trends

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As distributed generation, energy storage and smart homes gain traction, electricity supply, which used to be about providing a commodity, will increasingly become about providing a full suite of energy services. This will drive utilities to a niche for smart energy innovators. Utilities will also look to expand into e-mobility, with electric vehicles set to gain a greater share of the global car market.

Goldman Sachs Equity Research (2016) stated that the Low Carbon Economy is now as much a transformative tech shift as it remains a response to global environmental challenges. As the transition gathers pace, the risk markets face is low-carbon tech disruption, not necessarily carbon pricing. Industry dynamics in autos, utilities, capital goods, energy, and materials could be meaningfully affected. In the absence of large-scale, low-cost grid storage, natural gas could be a beneficiary of increased renewables penetration. The intermittent nature of renewable energy is disrupting the traditional division of labor in power generation, whereby large coal plants provide a steady supply of electricity, while gas plants adjust their output in line with fluctuations in the load. As gas is competitive in both base load and flexible generation, Goldman Sachs analysts see it as a structural beneficiary from this new environment. In high-penetration markets, such as Europe, regulators may move to subsidize the provision of gas-based backup capacity to guarantee grid stability.

According to Bloomberg New Energy Outlook 2017, it is expected $10.2 trillion to be invested in new power generation capacity worldwide to 2040. Of this, 72% goes to renewables, or $7.4 trillion. Solar takes $2.8 trillion and wind $3.3 trillion. Investment in renewable energy increases to around $400 billion per year by 2040, a 2-3% average annual increase. Investment in wind grows faster than solar – wind increasing 3.4% and solar 2.3% per year on average.

Gas-fired capacity increases 16% by 2040 but gas plants will increasingly act more as a source of flexible generation needed to meet peaks and provide system stability rather than as a replacement 'baseload' coal. In North America, however, where gas is plentiful and cheap, it plays a more central role, especially in the near term.

In Europe, gas benefits from a wave of coal and nuclear retirements over the next decade, but power sector gas consumption never returns to the record level set in 2008 as the role of gas shifts from providing firm capacity to providing flexible generation. Nuclear generation drops 50% and the combination of sluggish demand, cheap renewables, and coal-to-gas fuel switching slash coal use by 87% by 2040. This drives down power sector emissions by 73% over 2017-40.

Bloomberg also expects U.S. power sector emissions in 2030 to be 30% below 2005 levels, coming very close to fulfilling the Clean Power Plan's headline goal even in the absence of federal policy. The federal Clean Power Plan was anticipated to reduce power sector emissions by 32% below 2005 levels by 2030 and the U.S. pledge in the UNFCCC Paris Accord set an economy-wide goal of 26-28% below 2005 levels by 2025.

The large influx of intermittent renewable energy generation into European power markets has served to destabilize grid systems across the region and has had negative impacts on the utilities operating across the sector, deterring investment into necessary new thermal or nuclear capacity. However Nuclear power capacity will grow in emerging markets in 2018 while operating capacity will shrink in the US. Chinese and Russian companies will continue to gain shares in the competitive landscape for nuclear reactors in emerging markets

According to BP Energy Outlook (2017), in its base scenario, a central feature of the energy is the continued gradual decarbonization of the fuel mix. Natural gas is expected to grow faster than oil or coal, helped by the rapid growth of liquefied natural gas increasing the accessibility of gas across the globe. Oil demand continues to increase, although the pace of growth is likely to slow as vehicles become more efficient and technological improvements, such as electric vehicles, autonomous driving, and car sharing, potentially herald a mobility revolution.

Faster gains in energy efficiency combined with the gradual changes in the fuel mix mean the growth of carbon emissions from energy is expected to slow sharply relative to the past 20 years. Even so, the most likely path sees carbon emissions continuing to increase, indicating the need for further policy action. The timing and form of that action will have an important bearing on the nature of the energy transition. BP continues to believe that carbon pricing has an important role to play as it provides incentives for everyone - producers and consumers alike - to play their part.

3. CCUS Increasingly Important

Even considering the increasing penetration of renewables into the global energy mix, in fact, thermal generation, in the form of natural gas and coal-fired power stations, will retain a dominant position in the global power mix over a 10-year forecast period. Moreover, carbon-intensive industrial processes will remain widespread, with renewable technologies not viable as an alternative. Reducing the carbon emissions from existing power plants and industrial units will, therefore, be essential if countries around the globe are to hit their climate targets, as defined by the Paris Agreement. Consequently, CCUS remains crucial to the global effort to reduce carbon emissions, with most of the scenarios for limiting anthropogenic warming to less than 2 degrees Celsius incorporating a significant ramp-up in the use of CCUS technology.

According to Statoil's Energy Perspectives 2017, CCS features in most 2°C and "Well-below 2°C" scenarios. The Intergovernmental Panel on Climate Change (IPCC) estimates that reaching the 2°C target will be more than twice as expensive without CCS as with CCS. In IEA's 66% 2°C scenario CCS increases towards 3 Gt of CO_2 per year by 2050. Beyond 2050, CCS on biomass use is widely counted on to remove already emitted CO_2 from the atmosphere.

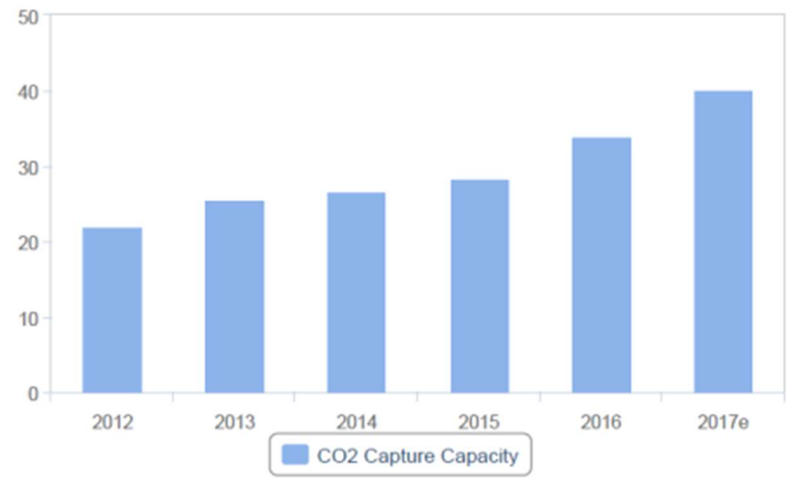

Figure 1. Global Carbon Dioxide Capture Capacity (mtpa)
Source: Global CCS Institute, BMI

Approximately 75% of the total cost of a CCUS system is tied to the CO_2 capture process, leaving significant opportunity for second generation research and development to reduce the costs and improve efficiency. CCS continues to edge forward. In 2016 a project to capture and store 0.8 million tons of CO_2 per year from an iron and steel plant – the first of its kind – was launched in Abu Dhabi. In January 2017, the US Petra Nova project designed to capture 1.4 mt of CO_2 per year from an existing coal power plant started operations. In March the first of several planned Chinese CCS projects targeting CO_2 from syngas plants received final investment decision, and in April the US Illinois Industrial CCS plant began operations. This project is ground-breaking because it is tied into a biofuels projects, capturing CO_2 from the processing of corn into methanol.

The most surprising news, however, comes from one least expected. According to MIT Technology Review, issued February 20, 2018, the budget bill that President Donald Trump signed into law provides a huge incentive for capturing and storing carbon emissions. Energy researchers who have crunched the numbers in the days since have concluded that on many projects the boosted tax credit could finally tip the scales for a technology that's long proved far too expensive. The measure provides a tax credit of $50 for every metric ton of carbon dioxide buried underground and $35 for every ton put to work in other ways. Companies will have six years to begin qualifying projects and a dozen from the time they begin operations to claim the credits. The estimated cost of carbon capture is about $60 per metric ton for coal-fired plants and around $70 for natural-gas plants, according to a 2015 report from the Office of Fossil Energy. Another $11 goes to transporting and storing the carbon dioxide. So, the tax credit still can't, in and of itself, offset the costs for the electricity sector today.

But it could make the financial difference for some plants tapping into other sources of subsidies, particularly as the price of carbon capture falls over the next few years.

4 - What About Carbon Pricing?

According to the TOTAL Report "Integrating Climate into our Strategy" (2016), clear economic signals over the medium to long term are vital to lower greenhouse gas emissions. Indeed, the French Oil Giant is supporting the introduction of carbon pricing mechanisms. Total considers that a price of between US$ 30 and US$ 40 per ton would both promote the switch from coal to gas and steer investment toward the technologies required to reduce emissions, such as carbon capture, use, and storage.

In the IEA World Economic Outlook 2017 the scenarios for carbon pricing range from US$ 15 up to US$ 140 (Table 1).

Table 1 – CO_2 price in selected regions by scenario ($2016 per tonne)
Source IEA WEO 2017

	Region	Sector	2025	2040
Current Policies Scenario	Canada	Power, industry, aviation	15	31
	European Union	Power, industry, aviation	22	40
	Korea	Power, industry	22	40
New Policies Scenario	South Africa	Power, industry	10	24
	China	Power, industry, aviation	17	35
	Canada	All sectors	25	45
	European Union	Power, industry, aviation	25	48
	Korea	Power, industry	25	48
Sustainable Development Scenario	Brazil, China, Russia, South Africa	Power, industry, aviation*	43	125
	Advanced economies	Power, industry, aviation*	63	140

5 - Gas Turbine Market Trends

Growing industrialization coupled with rising electricity demand will drive the global gas turbine market size over the forecast timeline. In 2015, natural gas has fueled over 25 percent of the total U.S. electricity generation. EIA is projecting that the country's present natural gas generation would exceed by 30 percent by the end of 2025.

Increasing investments towards the replacement of aging coal-fired plants with modern gas-fired power generating stations to limit the GHG emissions will upswing the global gas turbine market for the next decade. Indeed, Thermal Power will continue to dominate till 2026, as per BMI projections (Figure 2).

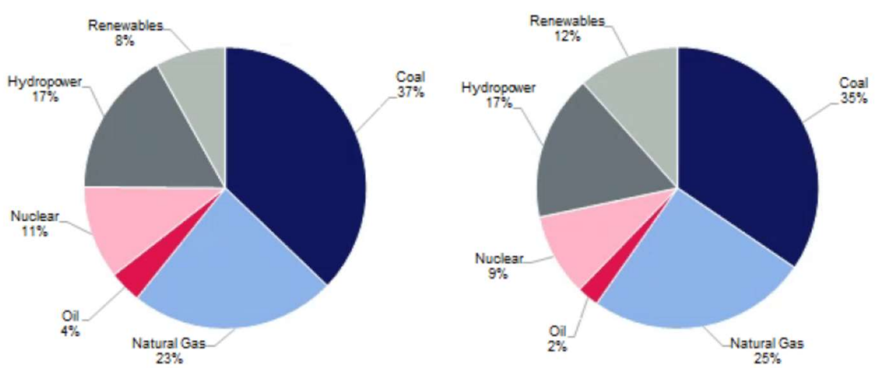

Figure 2 – Global Power Generation By Type 2016 (LHC) & 2026* (RHC), TWh
Source BMI Research

Global gas turbine market for heavy-duty accounted for over 80% of the global volume in 2015 owing to its wide acceptance across high capacity generating stations. Large capacity power plants hold the low generation cost which will positively impact the industry landscape.

Aero-derivative gas turbine market share is anticipated to witness significant growth over 9% during forecast timeframe owing to its rising demand across medium scale capacity applications.

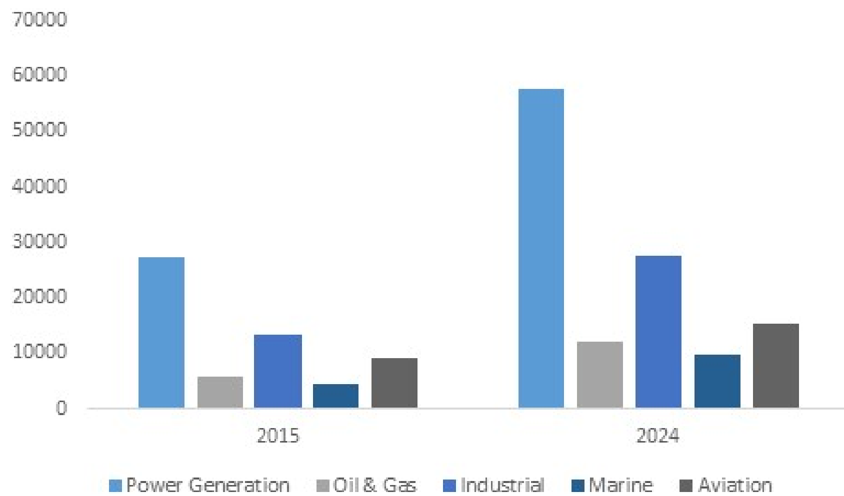

Figure 3 - Global Gas Turbine Market, By Application, 2013 - 2024 (MW)
Source: Global Market Insights Report (2017)

Gas turbine market volume for 70-300 MW is anticipated to witness a substantial growth of over 9% by 2024. Growing penetration of small-scale captive power generating facilities for reliable and affordable electricity supply will positively influence the business landscape. Above 300 MW capacity is set to exceed USD 8 billion by 2024. Growing applications across large capacity gas-fired power generating stations will positively impact the business growth.

Global gas turbine market from power generation accounted for over 40% of the global share in 2015. Growing adaption of clean fuel technology to limit the GHG emission will propel the business growth. Development of gas based microgrids across numerous countries including the U.S. will further augment the industry outlook.

O&G gas turbine market is set to witness a significant growth of over 6% by 2024. In 2017, GE unveiled new LM9000 aero-derivative gas turbine specifically designed for O&G with the aim to reduce NOx emission by 40%.

6 -Technology Trends - Supercritical CO_2 Power Cycles

The use of CO_2 as working fluid in thermodynamic cycles has been of studied and has gained momentum in the last decade. Carbon dioxide when in the supercritical state has properties such as high density and high specific heat, which makes the thermodynamic cycle highly efficient, with great reductions of space and weight (Figure 4), when compared to conventional cycles Brayton/Rankine. Cycles using CO_2 can be direct or indirect.

The example of a direct cycle that is in the most advanced stage is the so-called Allam cycle, also known as NET Power Cycle. The American company NET Power leads a consortium of companies in the implementation of a 50 MW demonstration-scale plant in the city of La Porte, Texas.

The ongoing studies for the Allam cycle project a cost of Levelized Cost of Energy ($/MWh) very competitive with the most efficient thermal plants. Direct cycles, such as Allam, CO_2 is produced continuously by the combustion with the pure oxygen of a given fuel, for example, natural gas. In this case, the products of combustion are CO_2 and H2O. This mixture is used as working fluid for expansion in a turbine for power generation. Thereafter the CO_2 is separated from the water and most of it is returned to the process and the surplus will be available for sequestration or use as feedstock for other processes.

For the case of indirect cycles, CO_2 goes through a closed cycle, and there is no surplus production. The heat is supplied to the cycle indirectly by means of heat exchangers. Due to these characteristics cycle the indirect heat input takes place at more moderate temperatures, in the range of 600 to 800 ° C, as compared Allan cycle where the direct heat is supplied to temperatures exceeding 1000 ° C. Due to these differences between the open and closed cycles, one can understand the main advantages and disadvantages of each cycle. If on the one hand the open cycle allows to obtain the greater efficiency, the higher temperature and pressure, and the combination of CO_2 and H2O, make the choice of the materials a great challenge.

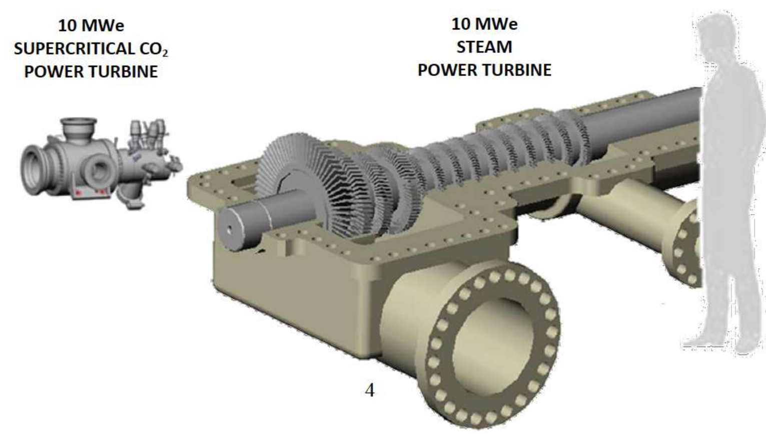

Figure 4 – Size comparison sCO_2 Turbine x Steam Turbine

On the other hand, the closed cycle, despite the lower efficiency, is less aggressive. The selection of materials for the indirect cycle is still challenging, but less so than in the case of the open cycle. The closed cycle does not capture the CO_2 of the combustion process. However, it has the capability to improve the overall efficiency of the cycle, besides the reduced footprint and weight, that can also lead to a reduced carbon footprint.

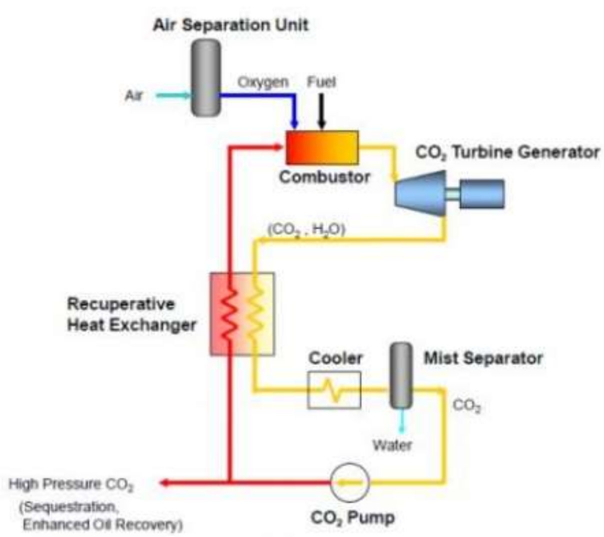

Figure 5 – Supercritical CO_2 Cycle with oxy-combustion

The challenges of the project are the selection of materials and the development of turbo-expanders for CO_2 supercritical at high temperatures. In addition, a rigorous analysis and simulation of the possible configurations of the cycle, aiming at obtaining maximum efficiency, considering the technological limitations. Therefore, it is necessary to determine the combination of variables that allow the maximization of efficiency with the lowest possible costs. In the literature, there are reports of several initiatives of research and development, in different degrees of maturity.

The American company NET Power is the leader of a consortium of companies in the implementation of a 50 MW demonstration-scale plant in the city of La Porte, Texas. The consortium had the participation of the laboratories of the Sandia National Laboratories and the Lawrence Berkeley National Laboratory. The consortium involves Toshiba, Echogen, Dresser-Rand, GE, Barber-Nichols, The Shaw Group and Exelon Corporation. The technology used in the project uses oxy-combustion direct cycle. Toshiba has designed and manufactured the combustor and CO_2 turbine. The consortium also intends to develop a project on a scale of 250 MW.

The Echogen Power Systems has developed an indirect cycle power generation waste heat recovery, cogeneration, geothermal and hybrid as an alternative to the internal combustion engine. The system uses a scalable platform technology is 250 kW at 50 MW, to meet the widest possible range of industrial applications. The technology is independent of thermal source, which means that it is suitable for a wide range of lime sources for energy recovery. Its application includes combined cycles with gas turbines, stationary generator sets for internal combustion engines, industrial waste heat recovery, solar thermal, geothermal and hybrid power plants.

The Southwest Research Institute in San Antonio, Texas, taking part of a project worth US$ 80 million funded by the US government (DOE). The objective of the project is to design, build and operate a 10 MW pilot plant. The plant will be installed on the SWRI campus. The project is led by Gas Technology Institute, a non-profit organization that uses government funds. The project is part of a larger US government program called "The Sunshot program". The project is co-sponsored by private initiative, with partners being General Electric, Thar Energy, and Bechtel Marine. The program aims to achieve the following goals:

• Net cycle efficiency > 50%
• Non- use of cooling water (air cooled)
• Cost <$ 1,200 / kW. (CAPEX)

The scope of SWRI includes the design and operation of the test and support loop. GE is engineering and manufacturing the turbo-expander. Thar Energy has as its scope the design of the heat recovery exchanger.

7 - Technology Trends - Carbon Capture, Transport, And Storage

Among the Carbon Capture Technologies, some are commercially available, and they have been demonstrated for a long time, in small scale. Some techniques have shown promising in demonstration and pilot projects. In some applications, gas production and processing for instance, where CO_2 capture is mandatory to keep the product under strict specifications, the CO_2 separation from the natural gas is available and very successful for many years. However, carbon separation is only the first step towards the path to a greener industry. The handling of the carbon captured is the critical step, whether it is to be sequestered, stored, or utilized as a raw material to produce other goods.

The available technologies are still very expensive and add significant complexity to the industrial systems. Even with the more optimist projections, it is not possible to envision a cost-effective solution applicable throughout the candidate applications. However, given the importance of coal and natural for power generation worldwide, and its potential impact on climate change, governments and international entities have been investing heavily in the development of new technologies to mitigate the CO_2 emissions.

There are alternatives for the industrial sector regarding the potential to utilize the CO_2 captured as input to the downstream industrial plants, fertilizers production, conversion to plastics, conversion to other solids or cement production. These are very promising alternatives given they add potential value to the carbon and prevent the necessity of the costly compression, transport, and injection for the storage process.

8 - The Cost Issue

Among the challenges for the Carbon Capture and Management, economics the most important. It is indeed possible to say that all other issues are related to a matter of cost-effectiveness. The increased costs of carbon mitigation technologies are related to additional capital expenditures.

According to the Texas Sustainable Energy Research Institute, the Levelized Cost of Electricity (LCOE), reported in recent DOE/NETL analysis, ranged from $116/MWh to $151/MWh, depending upon the type of facility and whether the application was for a new plant or a retrofit of an existing plant. Those figures shall be compared to an LCOE of $85/MWh for a new supercritical pulverized coal plant and a $27/MWh LCOE for the current fleet of power plants. Figure 6 shows a comparison of costs of electricity for different power generation configurations (DOE, 2010).

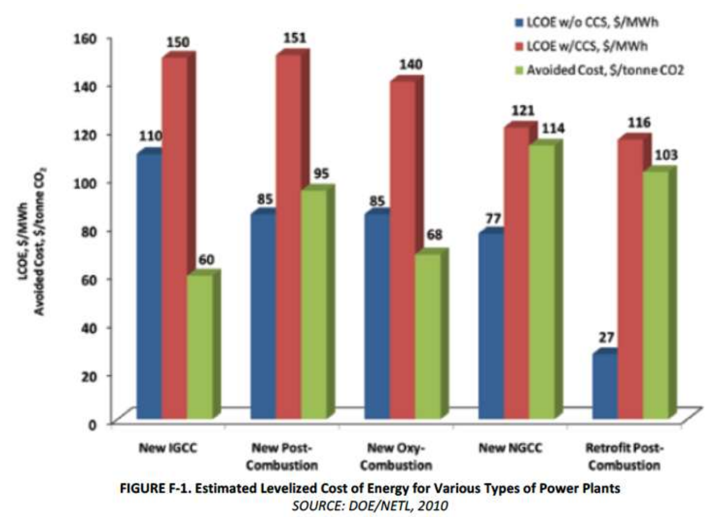

Figure 6 - Levelized costs of electricity for different power generation configurations.

Given the smaller scale of industrial plants CCS requirements, even considering the unfavorable effect of capital costs, some opportunities on the carbon utilization can be explored. The use of waste CO_2 as a feedstock of a new beneficial product or process is one of the possibilities.

9 - CCS Technology Drivers

Besides cost and economics, one primary driver for the development of CCSU technology is the continuous increase in awareness by the global society. Regardless whether the ideological or political will be favorable the path to a low-carbon society, it is the public opinion that may play the most important role. The awareness is increasing globally not only due to the publicity of the subject but due to the global warming effects that are already present.

It seems not wise for any entrepreneur nowadays not to include in their business models some value to be obtained by low carbon initiatives, being artificial incentives or even real value. The intangible benefits of today might be the actual profit of tomorrow. The cycle of incentives, scaled production, cost reductions, revenue, sustainable growth and the reinforcing effect of the enlightened global society will eventually, sooner or later, lead to the success of the CCSU technology. A good example is the Photovoltaics Energy. A few years ago, it was a space and astronauts only technology. Now it is the rooftops of many houses.

Of course, the challenge for CCSU is much bigger. Therefore, it will be mandatory to accelerate the pace of R&D and demonstrations project. It also seems that it is missing a real breakthrough technology to come about.

Give the heterogeneity of the carbon sources there is not a single approach for the CCSU deployment. However, the industrial sector presents excellent opportunities for carbon capture, especially for the carbon utilization, which has experienced a blossoming of good options, which can really add business value. The conversion of CO_2 into solid products, which already has a market developed, can make carbon capture feasible right away. Moreover, the solid products derived from the carbon capture has already a transport infrastructure developed, solving one of the major issues of CCS process.

However, our time is running out, and the pace shall be accelerated, in particular for Research and Development and demonstration projects. All over the world are good examples and not the most obvious ones, like Norway, Denmark, Germany, UK. Countries in the middle east like UAE and Saudi Arabia, also have ambitious plans to decarbonize its society. China is another major player, and they are already suffering from the effects of coal production, even if localized pollution due to particulates, it is a strong driver to develop CCSU.

Besides incentives, subsidies, taxes and carbon pricing, the continuous improvement of the global social awareness is the primary driver for the development of green technologies. Although the economic analysis so far discourages investments in CCS, the momentum is about to take off. The virtuous cycle of incentives, scale, cost-effectiveness, revenue, reinforced by an enlightened global community shall prevail.

10 - Hybrid Systems - The Role of Microgrids and Distributed Generation

Renewable Energy Technologies have had an exponential growth throughout the world not only because it is a low-carbon solution, with incentives and subsidies, but also because it became continuously cheaper and eventually a profitable business. As the renewable option has a significant share of solar and wind technology, it has an intermittent behavior. The misfit between load and supply poses additional challenges to the operation of the grid system. However, the development of microgrid technology, together with intelligent control and management systems, can improve the integration of the renewables and other distributed generation sources into the electric system. Although the terms smart grids and microgrids are not the same, both technologies are intrinsically connected. Indeed, the introduction of distribution sources close to the consumption sites has the advantage of increasing the reliability of the system and also, if properly managed, can improve the power quality by preventing voltage and frequency fluctuations.

Another significant trend to be considered is the projected increase in residential demand due to the development of the electric vehicles market. It has already been reported overloaded and congestion of distribution grids neighborhoods due to the simultaneous purchase of electric cars. The development of microgrids, connected to the main network, with distributed generation and storage systems, including some auto-production of energy by households, can save investment and costs associated with transmission infrastructure renovation.

The distributed features of microgrids as production, consumption, storage, and control shall consider a dual directional flow for both energy and information. Therefore, the system as a whole is complex and shall be managed with high-tech communication and computer systems, including smart metering and actuation devices.

As part of the solution to improve the system robustness, the development of competitive energy storage systems is mandatory. The improvement in the communication, software and system management provides the means for an efficient demand-side management. These are new concepts for system operation and control. Therefore, the system design shall take into account new planning, protection, and interactive control strategies.

The new smartgrid architecture will also require new performance paradigm, with new, more transparent, assessment tools. These features increase the need for awareness and commitment of stakeholders with the system design and implementation.

S&P Global Market Intelligence reports that "driven by the U.S. power sector's heightened focus on grid flexibility and the need to manage vast new volumes of variable renewable energy resources, a more dynamic class of power plant is emerging: wind, solar and fossil fuel facilities hybridized with battery storage". That is not new, but the numbers cited by S&P are impressive: "Roughly 80 such power plants are operating and planned to come online across the United States in the next few years, totalling 11,628 MW, according to S&P Global Market Intelligence data. That includes 4,433 MW of generating capacity at 50 existing power plants backed by 367 MW of battery storage capacity, most of which came online in the past two years. In addition, project developers have proposed adding another 820 MW of batteries at 31 planned and operating power plants with 6,008 MW of generating capacity.

11 - What About Hydrogen?

As pointed out by Stern et al. (2015) in the "Global Apollo Program to Combat Climate Change", the investment in energy storage shall be one of the top priorities. Hydrogen as a source of energy storage has been discussed for a long time, but it seems it has not yet conquered hearts and minds. According to the report, Hydrogen can act as a storage medium for electricity, but also as the source of power for cars and also be processed to produce other fuels. Figure 7 shows a simplified schematic Hydrogen production and integration with solar and other renewables.

Another seemingly interesting research has been conducted by Burhan et al. (2016). The research project has developed an experimental setup and a performance model to assess a concentrated photovoltaic (CPV) system to convert solar energy into hydrogen. According to the researchers, most of the studies have demonstrated that CPV is most suitable technology to produce hydrogen, with maximum efficiency. The studies have demonstrated a solar to hydrogen efficiency of 18%. For the long term, the CPV-Hydrogen system showed the average efficiency of 15.5% for 12 months. This performance represents a production of 218kWh/kg.

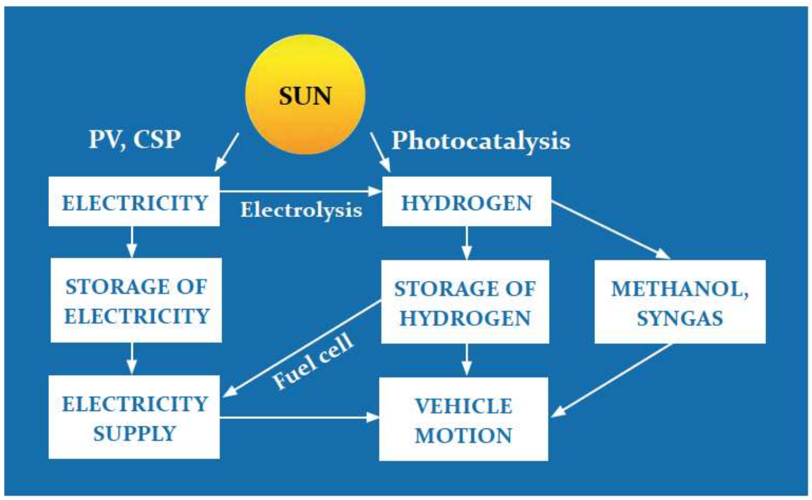

Figure 7 – Hydrogen production and integration with solar and other renewables (Stern et al, 2015)

12 - Conclusions

This paper has presented an overview of the main trends that will affect the turbomachinery technology, given the expected transition to a low carbon economy. The transition is already taking off based on technology disruption, even without carbon pricing incentives. The predicted scenarios present challenges but also opportunities to the turbomachinery community. The renewable energy intermittency offers good opportunities for natural gas-fired power plants. Despite the accelerated pace of cost reduction for megawatt size batteries, the hybrid solution is here to stay, given the existing and future natural gas infrastructure, both in pipelines and LNG. Besides, gas-fired generation is competitive in both base and flexible load and will continue to be in the next decades, with or without subsidies. Gas-fired capacity increases 16% by 2040 but gas plants will increasingly act more as a source of flexible generation needed to meet peaks and provide system stability rather than as a replacement 'baseload' coal. In North America, however, where gas is plentiful and cheap, it plays a more central role, especially in the near term.

As pointed out by BP Energy Outlook, faster gains in energy efficiency combined with the gradual changes in the fuel mix mean the growth of carbon emissions from energy is expected to slow sharply relative to the past 20 years. However, in the most likely scenario, carbon emissions will keep increasing. Therefore, carbon pricing has an important role to play. Indeed, carbon pricing is not only expected but supported by giant companies like Total and Statoil. It is a crucial step to make Carbon Capture and Storage feasible. And CCS itself is crucial to meet GHG emissions to keep the bellow 2oC target. Large-scale CCS will create a new market for centrifugal compressors and the process equipment associated, meaning another good opportunity. CCS will create jobs! Not only for the power market, but also for industries, cement, steel, chemicals. Besides incentives, subsidies, taxes and carbon pricing, the continuous improvement of the global social awareness is the primary driver for the development of green technologies. Although the economic analysis so far discourages investments in CCS, the momentum is about to take off. The virtuous cycle of incentives, scale, cost-effectiveness, revenue, reinforced by an enlightened global community shall prevail.

Other technology that will benefit from the green momentum is hydrogen, which can act as a storage medium for electricity, but also as the source of power for cars and be processed to produce other fuels. Again, this is a new market for turbomachinery, hydrogen turbines and compressors.

Among the technology trends, Supercritical CO_2 power cycle is disruptive. It is cost-effective, saves space and weight, and it is efficient. However, there are significant challenges ahead. The research is progressing with lab scale and demonstration units. It can take a decade or less, but this technology will be part of the transition, with complete new families of turbomachinery. The market for bottoming cycles, heat recovery in industries, wherever there is heat available there will a place for a compact device that can provide extra energy at zero fuel cost.

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