**Advanced Cycles**

With the rapid rise of renewables (in the European Union they account for about 80% of the new capacity in a 2030 scenario), there is a need to provide back up power and grid stabilization while

* increasing overall cycle efficiency
* reducing water consumption
* reducing CO2 footprint
* managing wear and tear on equipment due to intermittent usage

An answer to those needs are advanced cycles, not only looking at them from a pure thermodynamic point of view but also looking at system integration opportunities of different technologies that can cater to those needs. Considering current installed capacity (traditional power plants) will continue to serve in a 2030 energy scenario and beyond, particular attention will need to be devoted to upgrade and conversion applicability.

Because in most of the advanced cycles gas turbines are interconnected to other systems and components, or processes such as for example high temperature fuel cells or solar air heaters. Integration also often requires a change in mass flow rates of compressor or turbine as well as changing composition of the working fluid. Most GTs currently on the market are not designed for this type of process integration. R&D activities should therefore target developing concepts for easy to integrate and flexible gas turbines, as otherwise each cycle would need its specific gas turbine adaptation.

Because of changes in the chemical composition of the working fluid and the operating conditions the materials and coatings of the gas turbine have to be tested regarding their ability to withstand the new conditions. Most probably new materials and coatings have to be developed for specific advanced cycle applications.

For efficient and meaningful cycle evaluation reliable numerical simulation tools are needed.

* A tool or system of tools that allows the analysis of advanced integrated cycles without the need to manually iterate between power plant simulation and process modelling tools. This will avoid errors and should also result in a faster analysis and evaluation process.
* Tools well-suited for transient analysis of the process, as gas turbines are increasingly used to balance energy demand and the growing share of fluctuating renewables in the grid. Furthermore is it necessary to combine components of very different response characteristics in energy systems. Higher complexity and higher flexibility needs during start-ups and transients support this requirement.
* Tools for life cycle analysis in terms of costs as well as in terms of the environmental impact (CO2 and other emissions and impacts accumulated over the entire lifetime) as a base for standard evaluation of concepts.

Ranking high on the promising advanced cycles list, sitting at different Technology Readiness Levels, we can find:

* Wet cycles
* Alternative fluids
* Exhaust Gas Recirculation
* Allam cycle
* Hybrid cycles
* Power plants hybridization with batteries
* Low grade heat recovery with heat pumps

**Wet cycles**

processes with extraordinary high water content in the work fluid. Water might be either added before the combustor (e.g. humid air turbine or TopCycle (Figure 3), in the combustor itself (e.g. Cheng Cycle) or after it (e.g. for power augmentation).

Operation of the combustor close to stoichiometric conditions and with high water content influences the stability of the combustion process. Further R&D is needed to enable stable operation under changing operation conditions.

**Alternative fluids**

The use of other working fluids than air, such as supercritical CO2 or organic compounds such as cyclopentane, is an issue which requires additional R&D efforts. In this context topics of interest might be:

External heat source integration be it either coming from external combustion, allowing the use of various fuels and at the same time reducing the overall process complexity by avoiding extra efforts and components for fuel preparation/ treatment, CSP field or nuclear reactor.

High efficiency, high temperature heat exchangers with optimized heat transfer and, depending on the fluids used, possibility for easy cleaning to reduce the effect of degradation.

**Exhaust Gas Recirculation**

Using Exhaust Gas Recirculation (EGR) as a method and tool for enhanced CO2 capture and sequestration by increasing the content of CO2 in the exhaust gas of the GT is also a cycle under evaluation. EGR is already used by Mitsubishi Heavy Industries for NOx control in J-series GTs with a Turbine Inlet Temperature (TIT) of 1700°C. This technology is thus close to commercial use.

**Hybrid cycles**

Hybrid cycles, combining different electricity production technologies (e.g. fuel-cell/gas turbine hybrids (Figures 7 & 8)) or renewable based power generation with fossil fueled generation should also be developed better. The combination of solar heat input to a natural gas fired GT is a particular technology which shows great promise.

**Power plants with integration of storage**

Another system approach to solving the renewable intermittence issue is integrating existing power plants with storage capabilities, these could be either batteries (used both for storage and reducing needs for fast start ups) or high temperature heat storage systems (to be used at a later timebypassing the combustor or to reduce the necessary amount of fuel by preheating the working fluid).

**Low grade heat recovery with heat pumps**

Another systemic approach can be to couple heat pumps to existing power generation systems and upgrade the waste heat such that it can be used effectively with a bottoming cycle or to replace or supplement direct firing.