According to the U.S. Energy Information Administration (EIA), approximately 85% of electricity produced in the U.S. was generated by steam power plants in 2016. EIA 2016 data indicates that for each 1% improvement in cycle efficiency, about 0.6 Quads (0.6 quadrillion BTUs) of fuel can be saved annually, with a corresponding 35 million metric tonnes reduction in CO₂ emissions; or, equivalently, an additional 95 billion kWh of electricity can be generated. Currently, the average efficiency of such plants is approximately 36% (see figure 1); with higher efficiencies requiring significant expenditures in additional equipment, as, for example, in the case of combined Brayton and Rankine cycles.

Analyses show that if two-phase expanders and compressors that can operate with wet steam were implemented, efficiencies well above 50% can be reached without additional equipment. Based on an approximate 16% improvement over current average efficiencies (see figure 1), the use of two-phase expanders and compressors can reduce the fuel requirement by 10 Quad and annual CO₂ emissions by about 560 million metric tonnes, or increase yearly capacity by an additional 1.5 billion kWh of electricity with no additional fuel consumption.

The Rankine steam cycle has been used for decades as the primary engine for efficient, large-scale steam power plants. Various means have been employed to increase cycle efficiency including such things as heating steam to transcritical temperatures, multi-stage reheat and expansion, and multiple-stage feedwater reheat. Current technology and equipment face operational limits because of the need to operate turbines with dry steam and to operate pumps with liquid water.
No such limits exist when using the proposed RadMax® Two-Phase Compressor (TPC) and the RadMax® Two-Phase Expander (TPX). For example, in the case of the latter, the charge within each TPX chamber undergoes a closed system expansion due to the chamber volume increasing as the cam revolves around the shaft. Since the chambers are stationary, no bulk motion is imparted to the charge. Consequently, the erosion problems that are inherent when turbines operate with wet vapors are here precluded.

Analyses show that RadMax® technology positive-displacement, axial sliding-vane two-phase compressors and expanders can potentially improve power plant overall steam cycle efficiency by about 7% over the more efficient steam plants, or about 16% over the average plant (see figure 2). This gain in efficiency is primarily accomplished by replacing water pumps and low-pressure turbines with RadMax® TPC and TPX positive-displacement devices that are able to compress and expand wet steam, respectively. Use of these two-phase devices allow the pumping and expansion processes to proceed within the liquid-vapor dome, thus permitting selection of optimum start and end states that maximize the cycle’s efficiency (see figure 3). Additionally, this approach is less complicated and requires less equipment investment than other methods currently used to enhance steam cycle efficiency.
Although still early in the development process, initial estimates for replacing the low pressure feedwater pumps and low pressure turbines in existing lower efficiency power plants with RadMax® TPC and TPX devices show a payback period of 2 – 5 years.

More research and economic analysis is needed to determine exactly where the optimum operation point is for different size plants in order for the best technologies to be adapted.

Cycle efficiency improvements provided by the adoption of two-phase compressors and expanders offers the potential for smaller and less expensive, sub-critical plants to be as efficient as the most efficient large plants. This can result in more, smaller efficient plants being built closer to the demand instead of building fewer, more distance plants, consequently reducing the load on the distribution system and creating a more secure and responsive grid.

Piston and screw positive-displacement technologies have limited abilities when handling two-phase fluids and are less efficient in producing rotary power whereas the efficient rotary positive-displacement operation of the RadMax® axial sliding-vane technology is perfectly suited for two-phase compressor and expander steam applications.

The RadMax® rotary cycle (see figure 4) is better suited for steam expansion and compression applications due to the efficient positive-displacement operation, high output-to-size and weight ratio, ease of manufacturing, scalability, and the ability to handle two-phase fluids. RadMax® prototype expanders and compressors have already undergone testing with compressed air (see figure 5).

RadMax Technologies is currently planning the design, building and testing of a 25 - 50 kW proof-of-concept prototype compressor (TPC) and expander (TPX) capable of handling dry and wet steam of any quality.