ARPA-E Workshop: Topping Cycles for Higher Efficiency Power Generation

March 27, 2012
8:00AM – 3:30PM
Offices of Booz Allen Hamilton
3811 N Fairfax Dr, 10th Floor
Arlington, VA 22203

Objective

Identify technological whitespace, new research directions, and opportunities that could enable higher efficiency (> 60%) conversion of heat to electricity by developing devices that convert heat directly to electricity without moving parts. We envision that the hot side temperature should be > 1500°C and the waste heat/exhaust gasses are rejected ~ 1500°C into a Brayton cycle or ~ 600°C into a steam Rankine cycle. The topping cycle should have long life > 10 years and should raise the overall system efficiency > 60% (if the bottoming cycle is a combined cycle: Brayton + Rankine), or > 50% if the bottoming cycle is a steam Rankine cycle.

Introduction to the Workshop

In natural gas (NG) and integrated gasification combined cycle (IGCC) power plants, the combustion takes place with excess air so that the flame temperature is lowered from about 2000°C to ~ 1400-1500°C so it can be used in a Brayton cycle gas turbine. In conventional coal plants, the heat is downgraded to ~ 600°C so it can be used in steam turbines. This downgrading of the heat quality is counterintuitive to a major objective in the power industry, which is to raise the hot side temperature as much as possible so that the efficiency can be higher. The reason for throwing away the highest heat quality is due to a materials limitation, where there is a lack of materials that exhibit high enough mechanical strength and durability at such extreme temperatures to be used for turbomachinery components. This issue is fundamentally related to the fact that turbines only convert thermal energy to mechanical energy. Electricity is then produced, usually on the same shaft, in a separate generator/dynamo. One way to circumvent this temperature limitation is to consider adding another cycle that takes advantage of the higher quality heat by not having any moving parts, thus eliminating the need for high mechanical strength at such high temperatures. With the high strength requirement removed, there are many more materials that can survive and possibly produce electricity via another type of device. Currently, however, there are no devices that have been commercialized, that can work at higher temperatures than gas turbines. If such devices were to be developed it would have an impact from several different vantage points, and the goal of the workshop is to determine if there is whitespace in developing these devices to increase overall efficiency.

Potential Impact: In the context of NG and IGCC based power production, topping cycles could lead to an increase in overall power plant efficiency, which would subsequently translate to reduced emissions (Mton CO_2 emitted/kWh of electricity produced). It may be possible that a new device is developed that can supply enough additional electricity to a combined cycle plant, such that the additional output could cover the parasitic load required for an air separation unit (ASU). If this metric is achieved, it would enable oxy combustion and would significantly lower the cost of carbon capture by providing a pure CO_2 stream. Another potential impact is if a topping cycle can be developed for concentrating solar power (CSP). The primary challenge in CSP is to reduce the LCOE, which can be done by reducing the cost and increasing the power output of the plant. Today, in the case of NG, only ~ 500°C of heat quality is thrown away. In the case of CSP however, more than 4000°C is thrown away. The high temperature of the sun is the major fundamental advantage that solar energy conversion has over conventional fossil based production. This fundamental advantage, however, has yet to be exploited. If successful, the proposed program could lead to a topping cycle that makes CSP cost competitive with fossil fuels, without subsidies.

Workshop Agenda

Start Time	End Time	Activity	Speaker(s)/Officiate
8:00	8:10	Intro to ARPA-E	Ravi Prasher (ARPA-E)
8:10	8:30	Intro to topping cycles	Asegun Henry (ARPA-E)
8:30	8:45	Opportunities for Thermoelectrics	Gang Chen (MIT)
8:45	9:00	Opportunities for Thermionics	John Resenfeld (Thermacore)
9:00	9:15	Opportunities for High Temperature PV	Michael Piszczor (NASA)
9:15	9:30	Advances in High temperature Materials	Edgar LaraCurzio (ORNL)
9:30	9:40	Coffee Break	
9:40	12:00	Break out Session	
		Thermoelectrics	Dan Matuszak (ARPA-E)
		High Temp PV	Brian Borak (ARPA-E)
		Thermionics	Nick Cizek (ARPA-E)
12:00	1:00	Lunch	
1:00	3:15	General Session - White space and metrics	Asegun Henry (ARPA-E)
3:15	3:30	Wrap Up	Asegun Henry (ARPA-E)

<u>Ground Rules</u>

In the interest of time, the following topics <u>will not be discussed</u>:

1. Regulations, policies, subsidies and demonstration projects with existing technologies
2. Incremental improvement strategies to existing technologies
3. Ideas that would only accelerate down existing learning curves

ARPA-E's goals are to:

1. Validate or improve our ideas on appropriate metrics. We seek to be technically audacious, but set targets that are achievable with sufficient effort.

2. Identify and understand potential new designs, materials, and fabrication processes that could result in topping cycles that can improve energy conversion efficiency in various contexts of the stationary power sector.

Breakout Session Groups

GROUP 1: Thermoelectrics

Group 1 Breakout Session Questions:

1. Draw system level diagrams to show -- what are the different contexts/configurations where thermoelectrics might make sense to integrate into stationary power production?
2. Which of these configurations has the potential for the highest impact? Which configuration has the greatest technical challenge?
3. How would you design and integrate thermoelectrics into a NGCC plant as a topping cycle for maximum efficiency in the case of stoichiometric (2000°C) and oxy combustion (3000°C)? What are the most technically challenging aspects?
4. What are the important metrics for determining if a proposed thermoelectric topping cycle would add enough value to a new or existing power plant to be of commercial interest?

GROUP 2: Thermionics

Group 2 Breakout Session Questions:

1. How would a thermionic converter integrate into a CSP plant as a topping cycle?
2. If cost was not of concern, are there promising approaches to making thermionics with > 10% efficiency at hot side temperatures >= 2500°C, with > 10 year lifetimes?
3. Are there other promising directions for thermionics other than solar >=2500°C?
4. What are the important metrics for determining if a proposed thermionic topping cycle would add enough value to a bottoming cycle to be of commercial interest?

GROUP 3: High Temperature PV

Group 3 Breakout Session Questions:

1. Starting from scratch, how would you design a single junction and multi-junction cell to work at 400°C (trough) or 600°C (power tower)?
2. What are the most challenging aspects of redesigning cells for high temperature operation?
3. With sufficient time for development, how efficient do you think the cells could eventually be?
4. What are the important metrics for determining if a proposed high temperature PV cell operating as a topping cycle would add enough value to a bottoming cycle to be of commercial interest?