SAND2014-4780C

Spatial Variations in Temperature Across a Photovoltaic Array

Michaela G. Farr and Joshua S. Stein - Sandia National Laboratories

Introduction

The performance of a photovoltaic (PV) system is primarily affected by the irradiance and temperature of the array. The temperature of the array is generally assumed to be a function of irradiance, ambient temperature, and wind speed. For example the Sandia Photovoltaic Array Performance Model (SAPM) [1] assumes the following equation for prediction of the back of module temperature

$$T_m = E*\{e^{a+b*WS}\}+T_a$$

where:

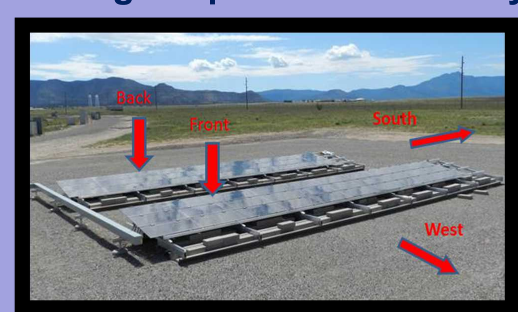
- T_m = Back-surface module temperature, (°C).
- T_a = Ambient air temperature, (°C)
- E = Solar irradiance incident on module surface, (W/m²)
- WS = Wind speed measured at standard 3-m height, (m/s)
- a = Empirically-determined coefficient establishing the upper limit for module temperature at low wind speeds and high solar irradiance
- b = Empirically-determined coefficient establishing the rate at which module temperature drops as wind speed increases

Research Goal

The goal of this research is to describe the observed thermal patterns of two arrays with identical set-ups in Florida and New Mexico and evaluate the possible causes of systemic variations.

Setup

Array composed of 60 modules arranged in a front and back rack. Each rack contains 30 modules arranged in 5 electrical strings of 6 modules each. The modules were connected in series and the strings in parallel. The array is tilted 10 degrees to the West.



Sandia National Laboratories NM Array

S6		S7		S8		S9		S10	
16		15					11		
			14			12			9
				13				10	

S1		S2		S3		S4		S5	
		6					2		1
8			5			3			
	7				4				

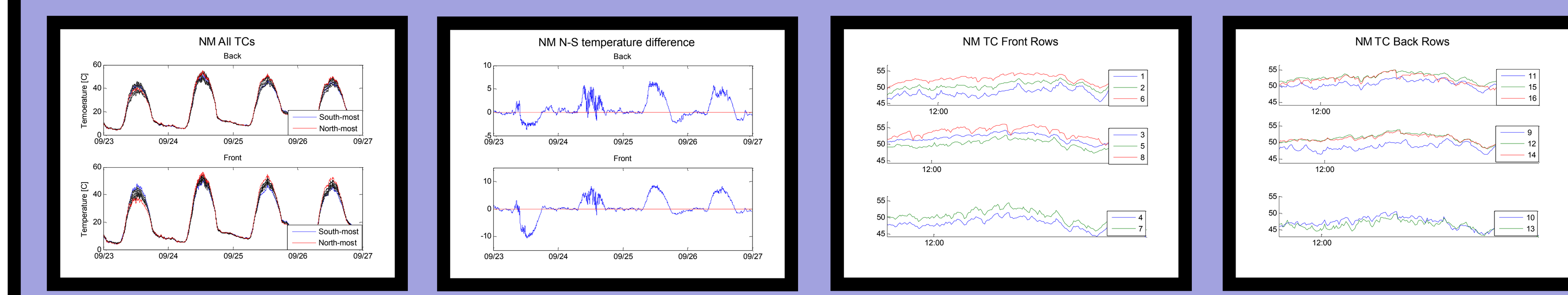
Positions of modules, thermocouples, and strings

Wind speed, wind direction (taken at 10 meters), and irradiance were gathered every minute and evaluated for several clear sky days. Minute temperature data was gathered using 16 thermocouples in the positions shown. All temperatures were corrected using a night time calibration factor.

Preliminary Results

NM Sample Days: 9/23-9/26

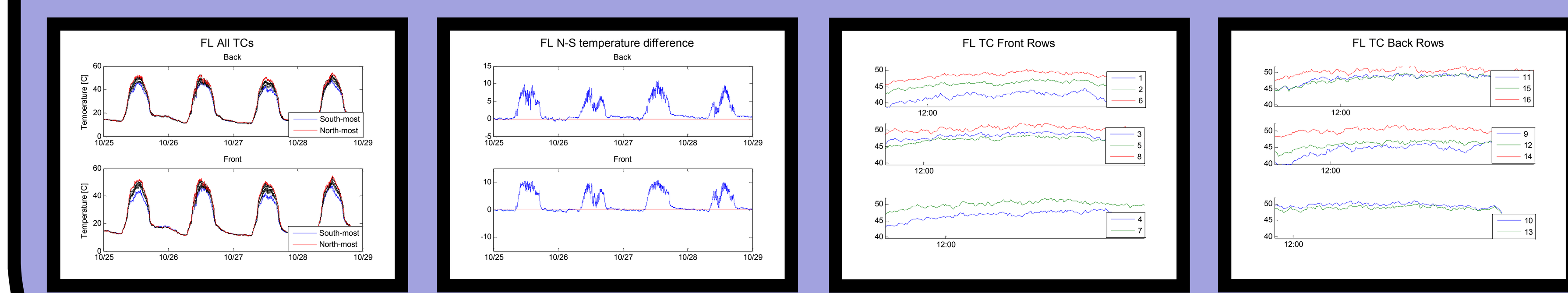
Several consecutive clear sky sample days were examined for each site.



Overlay of All TCs — North-South Temperature Difference — Individual Strings in Rows (Front) — Individual Strings in Rows (Back)

FL Sample Days: 10/25-10/28

It was found that for a given day there could be as much as a 10 degree temperature spread at either site.



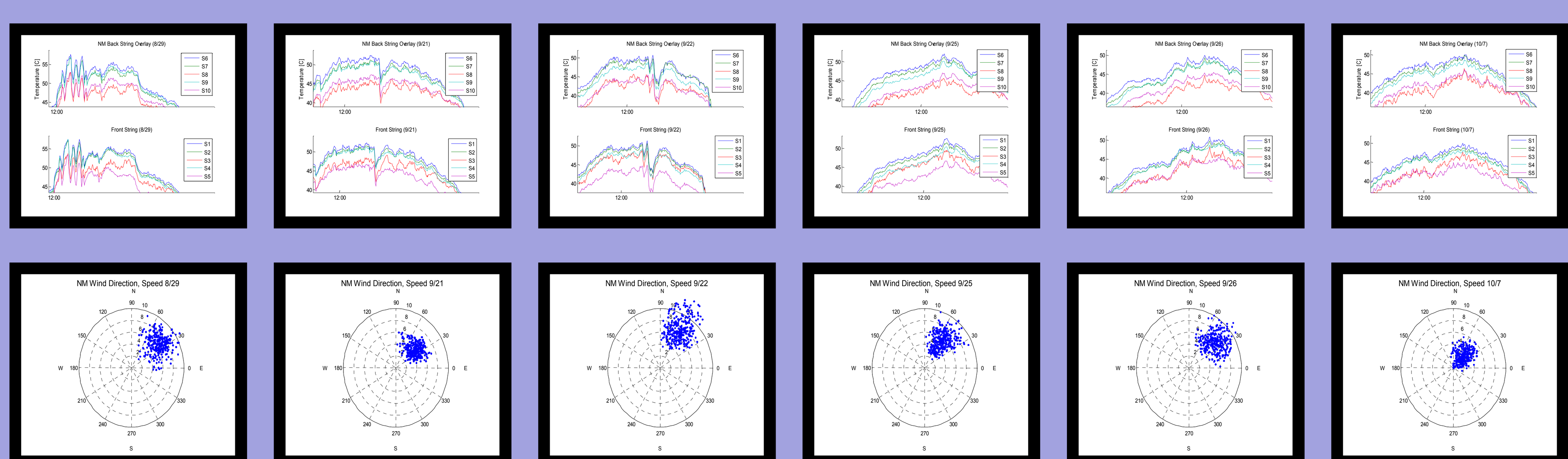
Overlay of All TCs — North-South Temperature Difference — Individual Strings in Rows (Front) — Individual Strings in Rows (Back)

This prompted us to examine wind as a potential culprit

New Mexico Wind Influence on Electrical Strings

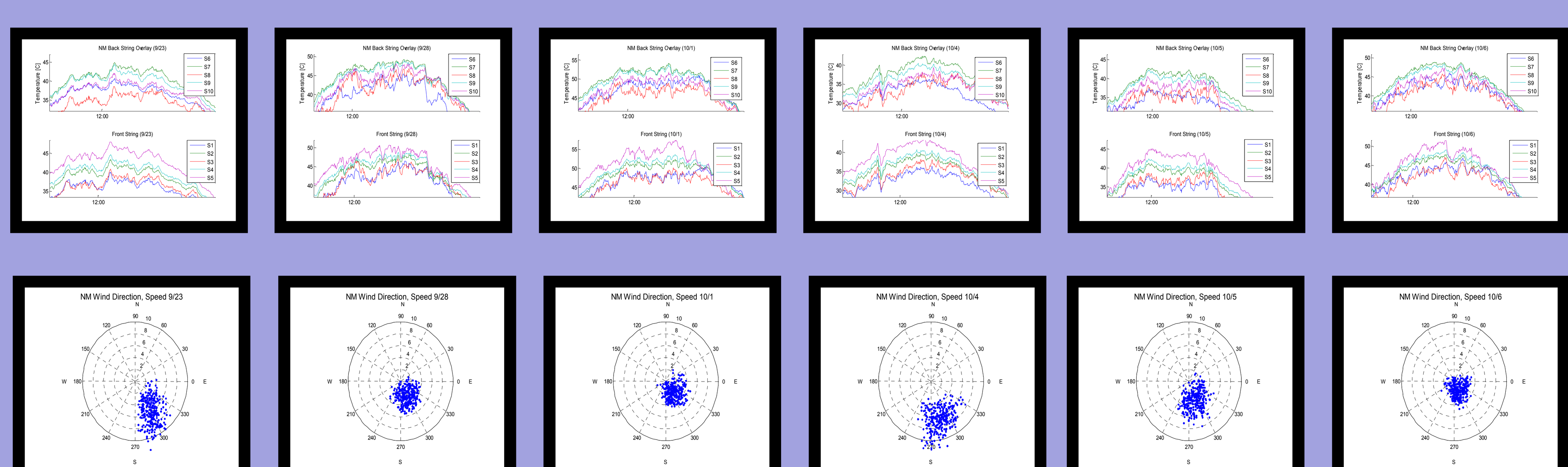
Northeast Wind

Wind roses and string temperature plots for 12 NM days with northeast and southeast prevailing winds. North-most strings:S6 & S1, South-most strings: S5 & S10



Southeast Wind

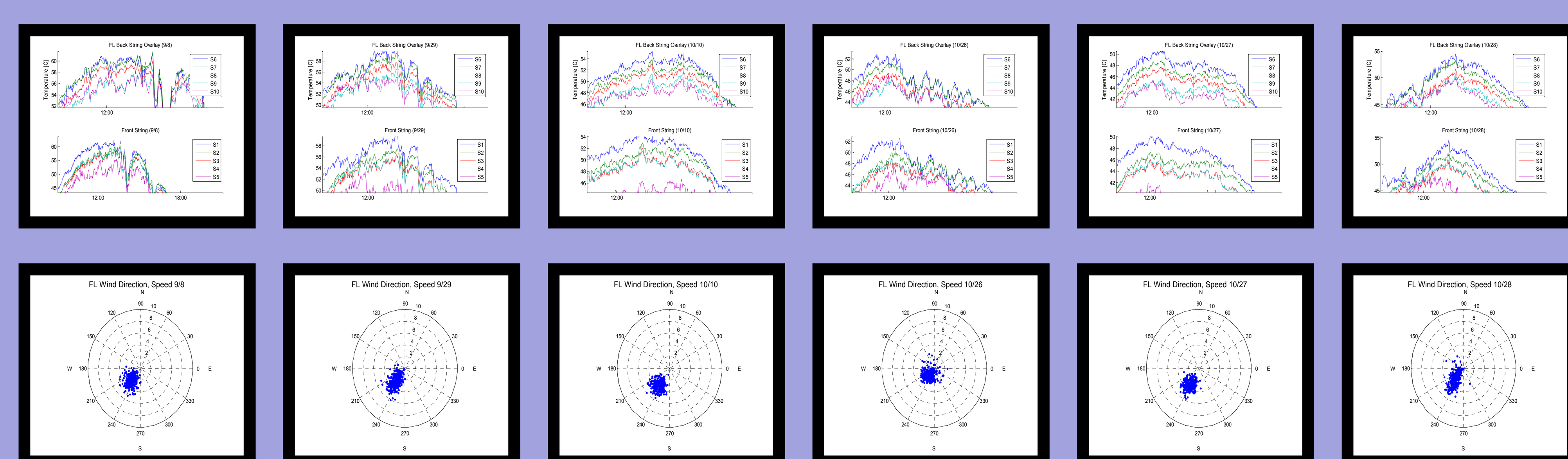
Wind from the northeast seemed to cause northern-most strings (S6 and S1) to be warmest with temperature generally decreasing from north to south. Wind from the southeast tends to cause the a reversal of this trend with S5 and S10 among the warmest.



Florida Wind Influence on Electrical Strings

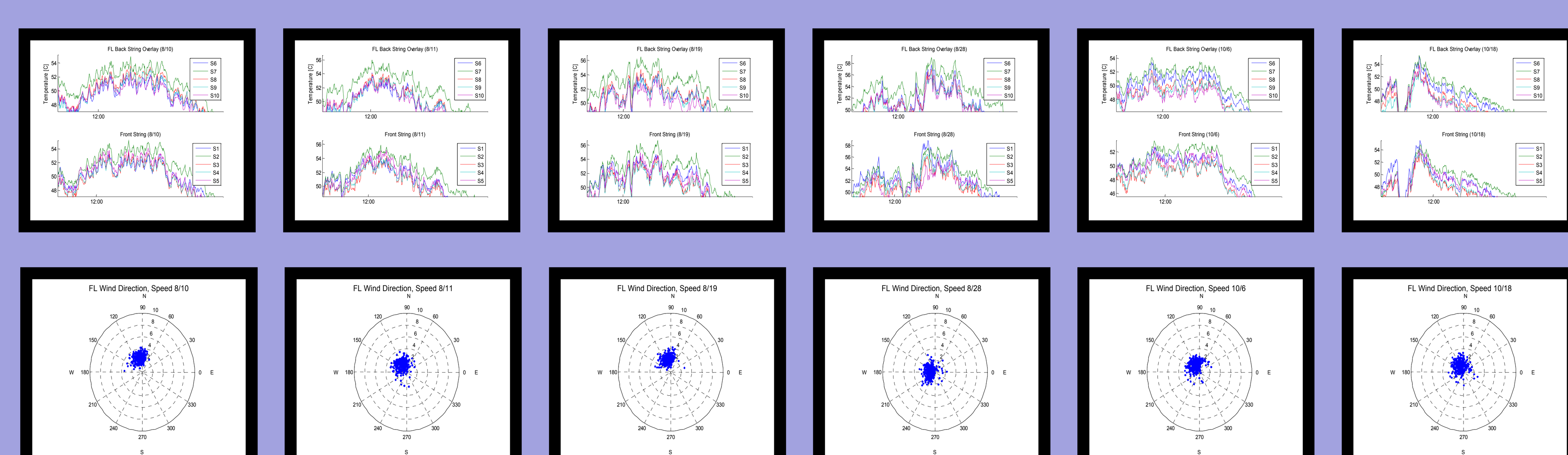
Southwest Wind

Wind roses and string temperature plots for 12 FL days with southwest and northwest prevailing winds. North-most strings:S6 & S1, South-most strings: S5 & S10



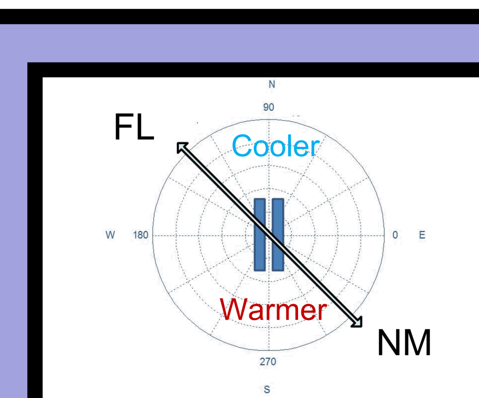
Northwest Wind

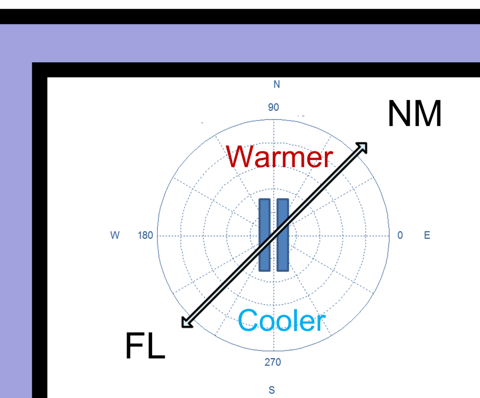
Wind from the southwest seemed to cause an obvious linear temperature decrease from north to south (S6 and S1 being the warmest), similar to the trends shown in NM for northeast wind. North west wind seemed to cause a general reversal of this trend, similar to the New Mexico southeast wind.



Results and Conclusions

Wind from the northeast and southwest in New Mexico and Florida, respectively, seemed to cause similar trends in spatial temperature variation. The northern-most modules were consistently warmest while the southernmost were generally coolest with all of the other modules falling somewhere in between. When wind blew from the southeast in NM and northwest in FL the modules exhibited the opposite tendency with the southernmost end being consistently warmest and the northernmost the coldest. Array temperature variations for both sites were shown to be as much as 10 C. PV performance models assume that array temperatures are uniform. Our study indicates that this assumption does not hold for these arrays. Although temperature patterns appear to be correlated with wind direction at each site, the correlations are different at each site. A different experimental design would be needed in order to explain this discrepancy.





Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. This work was funded by the US Department of Energy Solar Energy Technologies Program.