

Seminar on Ultra-High Temperature Systems

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Aula C - Escuela Técnica Superior Ingenieros Industriales
(Universidad Politécnica de Madrid, UPM)

Organized by Luis F. González-Portillo (associate professor at UPM, visiting researcher at MIT)

Speakers

Michael Bichnevicius (researcher at MIT)

Shomik Verma (researcher at MIT)

Kyle Buznitsky (researcher at MIT)

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Thermophotovoltaic systems for cost-effective, dispatchable, clean power

Shomik Verma

Thermophotovoltaics (TPVs) convert light radiated from a hot object into electricity using photovoltaic cells. TPVs can utilize cheap, mass-manufactured photovoltaic cells, making them potentially cost-competitive with fossil fuel-based power generation. However, their system costs have not been rigorously evaluated. This talk addresses that gap by deriving the cost of TPV systems based on their levelized cost of electricity (LCOE), determining whether efficiency or power density is more important in cost reduction. A TPV model is also developed to assess how improvements in physical cell properties affect LCOE. Results show that with inexpensive heating and low-cost cells, a TPV efficiency of 40% and power density of 5 W/cm² can yield a competitive LCOE of 8¢/kWh. We then explore how these performance metrics can be achieved. While efficiency and cell manufacturing have largely been solved, power density and low-cost heating systems remain key challenges. To improve power density, we note that high-temperature materials like refractory metals typically have low emissivity (~0.5). By using femtosecond laser pulses to create micro-scale texturing on emitter surfaces, emissivity can approach unity (~0.98), effectively doubling light output. We integrate these materials into TPV systems, demonstrating a doubling of power density at high temperatures, and then analyze emitter degradation and lifetime. Finally, we discuss low-cost heating solutions, including hydrogen combustors and thermal energy storage systems, which achieve a levelized cost of heating around 3¢/kWh-th. With these advances, the potential of TPVs for cost-competitive power generation can be realized.

Shomik Verma is a fourth-year PhD candidate in Mechanical Engineering at MIT, working with Prof. Asegun Henry as a PD Soros and NSF GRFP fellow. His research focuses on designing high-performing thermophotovoltaic systems for clean, dispatchable, cheap power generation. Prior to joining MIT, he was a Masters student at Imperial College London and University of Cambridge, where he worked on design and fabrication of photon conversion materials as a Marshall Scholar. He completed his undergrad from Duke University, where he broke two Guinness world records for vehicle efficiency with the Duke Electric Vehicles team.

Sun in a Box: Engineering Thermal Batteries for Ultrahigh Temperatures

Kyle Buznitsky

To meet the energy demands of the modern world with mainly electricity generated from solar and wind power will require an unprecedented amount of energy storage or other balancing technologies to deal with renewables' intermittency. Few storage technologies are cheap enough to be cost competitive with natural gas peaker plants and able to scale to the size of the problem in the timescales required. One particularly appealing storage method is thermal energy storage, where electricity is used to heat up a large insulated thermal mass, which is kept hot for hours or days at a time. When renewables production drops, the thermal battery can then use a heat engine to convert its heat to electricity for use. One promising iteration of thermal batteries is the Thermal Energy Grid Storage (TEGS) concept, where heat is stored in large graphite blocks at temperatures up to 2400°C, moved through the system by pumping molten tin, and converted back to electricity with thermophotovoltaics. The focus of this work is developing a laboratory scale prototype of the TEGS system, as well as identifying and overcoming system integrations challenges related to these extreme conditions and interacting subsystems.

Kyle Buznitsky is a PhD candidate in the ASE Lab advised by Dr. Asegun Henry. He works on developing thermal energy grid storage (TEGS), a long-duration thermal energy storage technology for the electricity grid that can enable greater use of renewable energy sources like solar and wind. His research focuses on designing and testing a laboratory-scale prototype of the TEGS concept to better understand the engineering and technical challenges that will arise as the technology scales. He is also interested in applying thermal energy storage to the challenge of decarbonizing industrial process heat.

Lower Cost, CO₂ Free, H₂ Production From CH₄ Using Liquid Tin

Michael Bichnevicius

Currently, hydrogen production is responsible for 2-3% of global CO₂ emissions which predominantly come from steam methane reforming (SMR). Methane pyrolysis (MP) can produce H₂ at a cost equal to or less than SMR, because instead of producing CO₂ as a waste byproduct with liability value of >\$50/ton the proposed process instead produces solid carbon which could be more valuable. The novelty and significance of our pyrolysis approach is the fact that it has never been possible until now. This is because it leverages a number of key technological innovations developed by the PI-Henry team within the last 5 years, namely the ability to pump and contain liquid metals such as liquid tin at extremely high temperatures > 1400°C. Since tin is inert with respect to both carbon and hydrogen, it can be used as a heat transfer fluid in a high temperature bubble column reactor that does not need a catalyst. This talk describes the development of a prototype MP reactor and challenges of working at high temperatures.

Michael Bichnevicius is a Mechanical Engineering PhD candidate in the ASE Research Group at Massachusetts Institute of Technology. He researches clean energy technologies including concentrating solar power and methane pyrolysis.