How can modern control techniques and preview be used to improve energy management in constrained systems?

- Modern vehicles are a heterogeneous mix of complex interconnected systems of various energy domains
- Electrification of many systems is resulting in increased power loads and thermal waste heat
- Enhanced optimization of power generation, distribution, storage, and utilization can be achieved using dynamic model-based control to improve performance and efficiency while preventing thermal runaway

**Vision:** With intelligent decision making the power density of existing electro-thermal systems can be improved by a factor of 2

### Optimization & Control Methodology

#### 5-Level Control Hierarchy
- Matches the natural hierarchy of many mobile systems
- Handles temporal and functional separation of systems, subsystems, and components

**Key Features**
- Event-based control updates
- Top-down information flow allows for effective planning of system states
- Bottom-up information flow allows for effective disturbance estimation
- Controllers use robust Model Predictive Control (MPC) or Genetic Algorithms
- Higher-level controllers
  - Plan an efficient path using large prediction horizons
  - Select mode of operation for lower-level controllers
- Lower-level controllers employ fast optimization (i.e. Explicit MPC)

#### Main Results

**Controller Development**
- Select candidate architecture
- Represent the architecture as a directed graph by analyzing how power flows through the system
- Partition graph based upon time constants
- Partition graph into various systems & subsystems based upon functional purposes
- Develop individual controllers and determine information flow

**Graph Model of Candidate Architecture**

Edges capture power flow, vertices represent system states.

**System Disturbances**
- Electrical Loads & Thermal Sink Temperatures

**System States**
- Electrical & Aircraft System Temperatures

**Preliminary Results**

**Control Hierarchy**
- Vehicle: Determines state trajectories for slow time scale dynamics and sends those commands to system level controllers. Has some knowledge of disturbances.
- System: Tracks vehicle level commands and determines state trajectories for medium time scale dynamics which are passed to subsystem level controllers.
- Subsystem: Tracks system level commands and determines state trajectories for fast time scale dynamics. Also measures plant states and communicates that information up through the hierarchy.

**Developing controllers within the hierarchy**

**Graph partitioning**