This research relies on the combined framework of a MATLAB®-based tool for the development of train trajectories with a MATLAB®/Simulink®-based tool that allows for a detailed analysis of the energy flows throughout the train’s drive system, resulting in a “bottom-up” (i.e. beginning with the wheels) assessment of power/energy requirements and fuel consumption.

The MATLAB®-based Single Train Simulator (STS), developed by the University of Birmingham (UK), uses a combined forward/backward distance-based technique for the production of parameterized speed profiles for user-defined route and vehicle characteristics. It uses train kinematics and Euler’s method to develop duty cycles, taking into consideration speed, acceleration and power limitations. (The “STS” has been utilized in several studies in Europe for the development of trajectories over specific routes and calculation of power and energy requirements at the wheel.)

Passenger railroad has been on the upswing (APTA/Amtrak). As this mode of travel continues to thrive, reducing emissions from rail will depend largely on fuel technologies (as with automobiles) This research, which will eventually also incorporate freight rail, is utilizing a simulation tool (known as a “Single Train Simulator”) to estimate fuel consumption from a variety of powertrains, including a “benchmark” diesel, a hydrogen fuel cell, and each of these hybridized via batteries (so as to fully take advantage of regenerative braking).

**RESEARCH QUESTION**

Passenger railroad has been on the upswing (APTA/Amtrak). As this mode of travel continues to thrive, reducing emissions from rail will depend largely on fuel technologies (as with automobiles). This research, which will eventually also incorporate freight rail, is utilizing a simulation tool (known as a “Single Train Simulator”) to estimate fuel consumption from a variety of powertrains, including a “benchmark” diesel, a hydrogen fuel cell, and each of these hybridized via batteries (so as to fully take advantage of regenerative braking).

**FUELS BACKGROUND**

**Diesel-Electric:** Currently powers approximately 87% of all domestic rail service (US DOE, 2013). >99% of freight rail operations.

**Hydrogen/Fuel Cell:** Fuel cells produce zero pollutant or GHG emissions at the “tail pipe,” and are more efficient than ICEs. This reduces the fuel requirement and, potentially, the cost, though hydrogen, where available, is currently rather expensive.

- **Regenerative braking:** Even in liquid form, hydrogen’s per gallon energy density is much lower than diesel fuel. Fuel cell stack lifetime is another area of concern; however, one AC Transit (SF Bay Area) bus has a stack in operation that has required no major overhauls despite nearly 21,000 hours of operation.
- **Emissions from hydrogen could vary tremendously depending on the source of the hydrogen (e.g. natural gas reformation predominating vs. reliance on various renewable methods).**

**Hybridization** - A hybrid vehicle has a primary power source and an on-board energy storage device.

- **Primary power source/power-plant:** E.g. Combustion engine (diesel) combined with electric generator, Fuel cell
- **Storage device:** E.g. Batteries, Flywheels, Supercapacitors

**Benefits:**
- Capture regenerative braking energy
- Operate prime mover (especially an engine) in its optimal zone(s)
- Opportunity to downsize the prime mover

**SIMULATION APPROACH**

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Kinematic equation: \( m \left( I + \frac{dL}{dt} \right) = TE - mg \sin(a) + C \left( \frac{d\omega}{dt} \right) + B \left( \frac{d\omega}{dt} \right) + A \)

Locomotive Characteristics:
- Maximum Speed: 125 mph
- Rated Voltage: 1080 V @ 50 Hz
- Rated Power (Max): 4,400 hp @ 1,800 rpm
- Operating Range: 600 to 1,800 rpm
- Head End Power: 350 kW
- Tractive Effort (Max): 65,000 lbs / 290 kN

**PASSENGER ROUTES/CHARACTERISTICS**

**EARLY STAGE CAPITOL CORRIDOR SIMULATION CHARTS**

**RESEARCH NEXT STEPS**

- Examine Caltrain, one switcher route, and two U.S. mainline freight routes
- Examine costs of different scenarios
- Analyze lifecycle CO2 and pollutant impacts

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