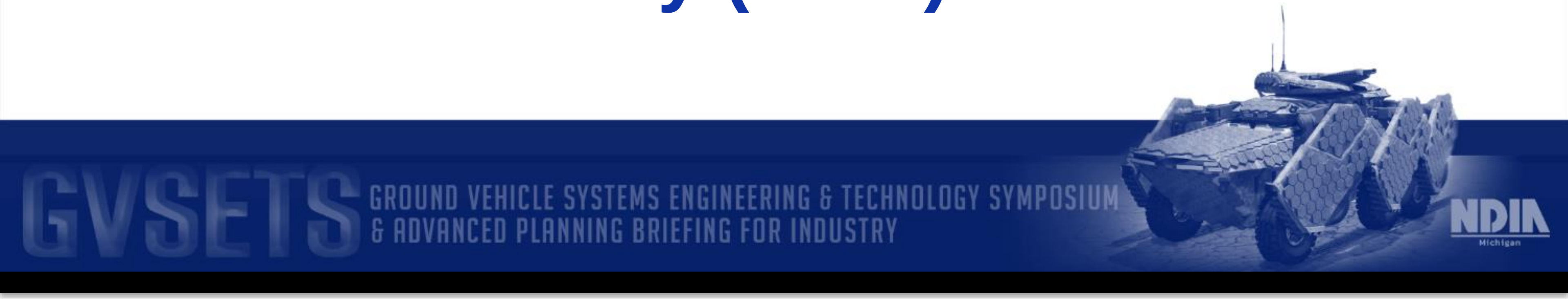
Power & Mobility (P&M)



Drive Cycle Modeling of Series and Parallel Hybrid Architectures for the Bradley Fighting Vehicle

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Agenda

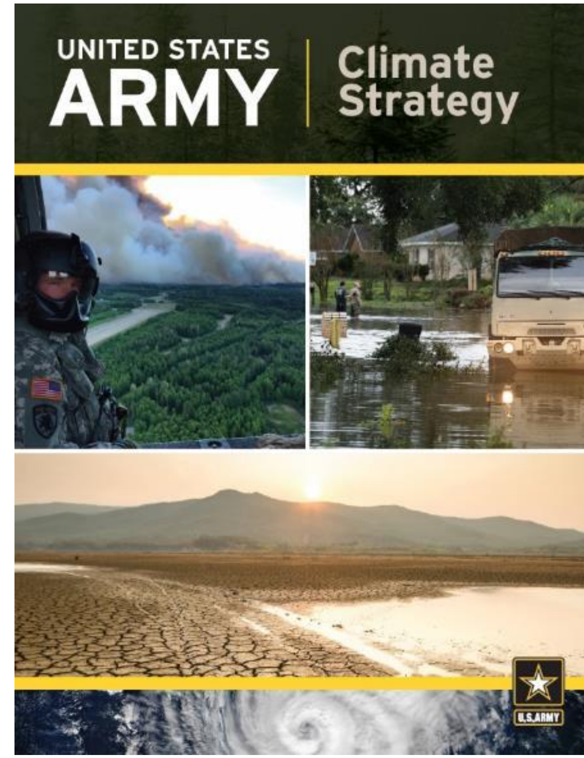
- Background
- Overview of the Bradley Fighting Vehicle
- Move to Electrification
- Hybrid Architectures and Components
- Drive Cycle Analysis and Model
- Model Results
- Hybridization Challenges
- Conclusions

Background – M2A3 BFV

- Used since 1981 as a troop transporter and tank killer
- Undergone three major revisions.
- Current version shares a platform with the AMPV and Paladin.

Background – Move to Electrification

- Secretary of the Army Wormuth stated that one of her main priorities is to combat climate change.
- Army released its climate strategy earlier this year.
  - Electrification of the non-tactical fleet by 2035
  - Field hybrid-drive tactical vehicles by 2035
  - Fully electric tactical vehicles by 2050

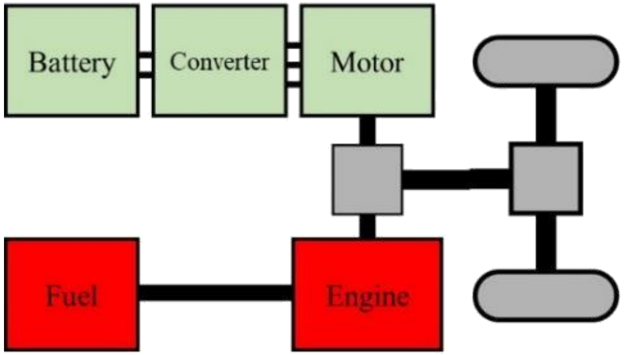


Benefits of Hybridization

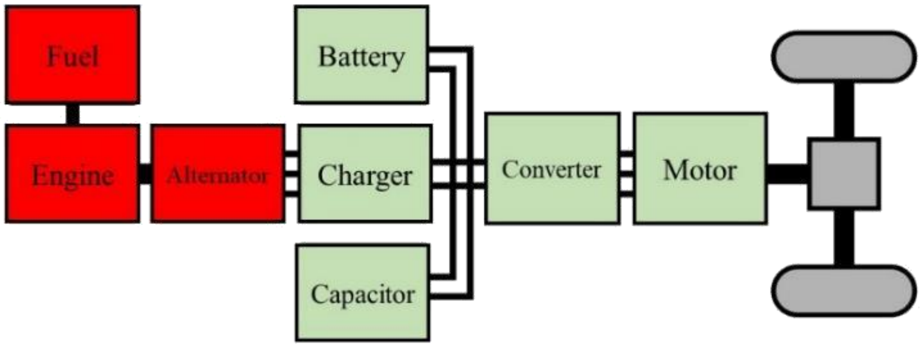
- Full electrification would be difficult given weight, volume, and range issues
- Full electrification offers little sustainability benefits for combat vehicles
- From a tactical standpoint, hybridization makes substantial sense.
  - Lower fuel consumption
  - Improved torque at low speeds
  - Increased range
  - Silent running options
  - Lower heat and noise signatures

Hybrid Architectures

- Parallel and Series architectures are commonly used for hybrid vehicles.
- Parallel → locomotion can be provided by engine or motor (most common configuration)
- Series → locomotion provided only by motor



Parallel Hybrid Architecture



Series Hybrid Architecture

Hybrid Components

Parallel Option

- Engine and transmission replaced with newer components with increased power density → frees up 16 cubic feet.
- Motors and accessories comparable to those used for a Tesla Roadster (produces 825 hp)
- Extra space allocated to batteries → 400 kg of batteries

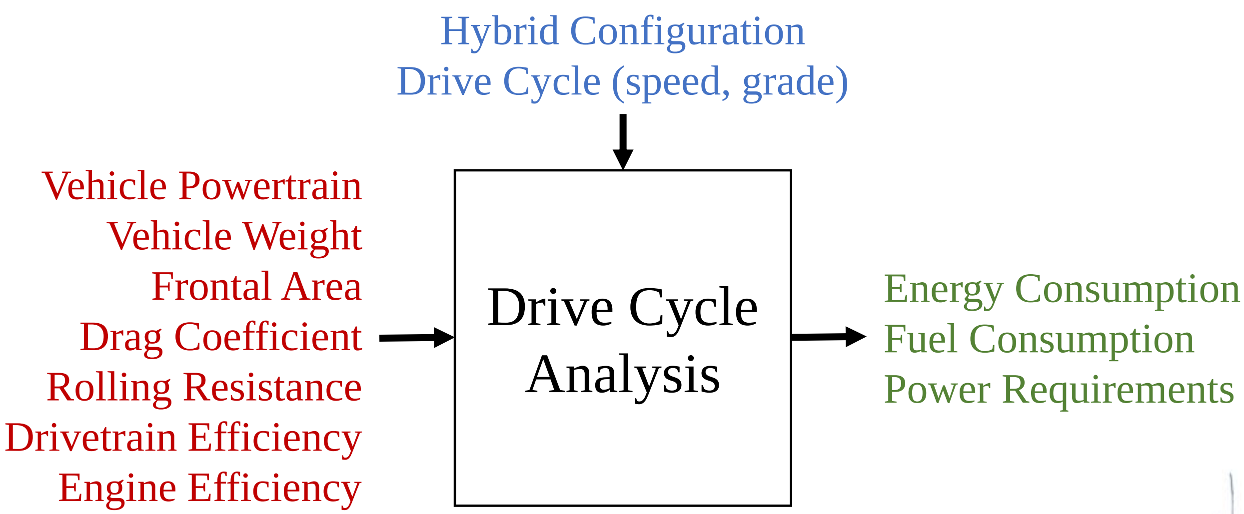
Series Option

- Newer engine with no transmission → frees up 25 cubic feet.
- Similar components to Tesla Roadster for motor and accessories. Additionally, large generator requirement.
- Extra space allocated to batteries → 1500 kg of batteries

Vehicle weight increases are factored into analysis. However, overall impact is minimal.

Drive Cycle Analysis

- Excel-based model to approximate fuel consumption for a given drive cycle.
- Based on load analysis for vehicles (acceleration, grade, rolling resistance, drag, accessories, cooling).
- Intended for comparative analysis.

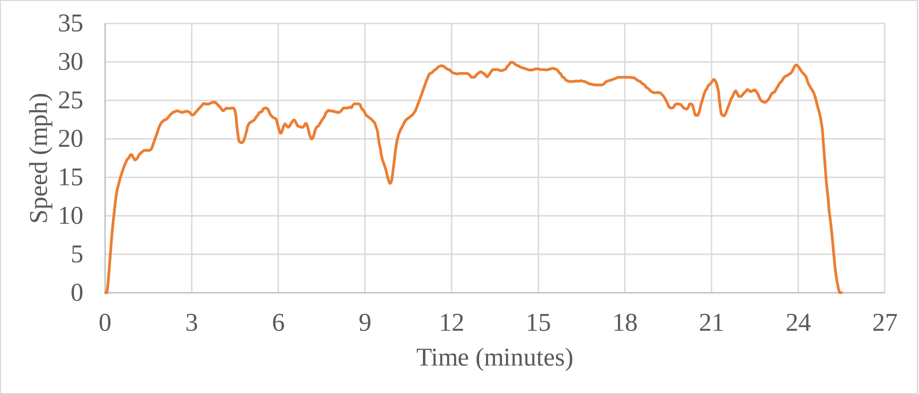


Drive Cycle Analysis - Model

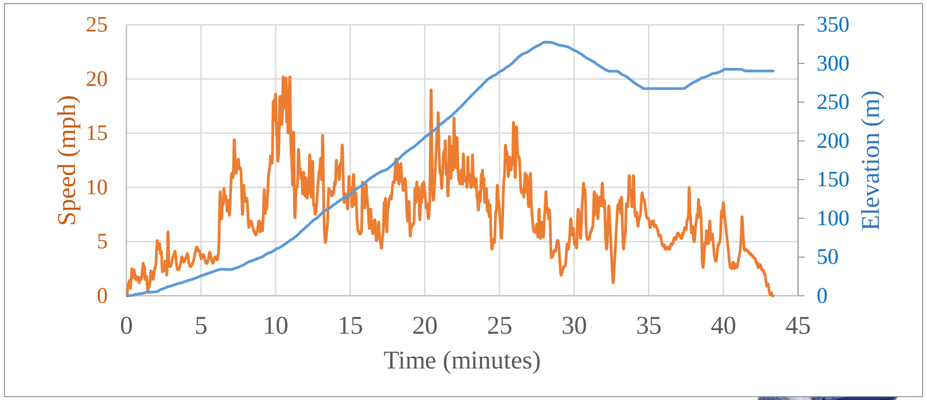
Power & Mobility (P&M)

- Drive cycle 1: Vehicle is stationary with a constant electricity draw of 5 kW
- Drive Cycle 2: Modified highway drive cycle (same distance profile with velocities scaled to reflect 30 mph top speed of BFV)
- Drive Cycle 3: Off-road drive cycle collected from vehicle data at NTC.

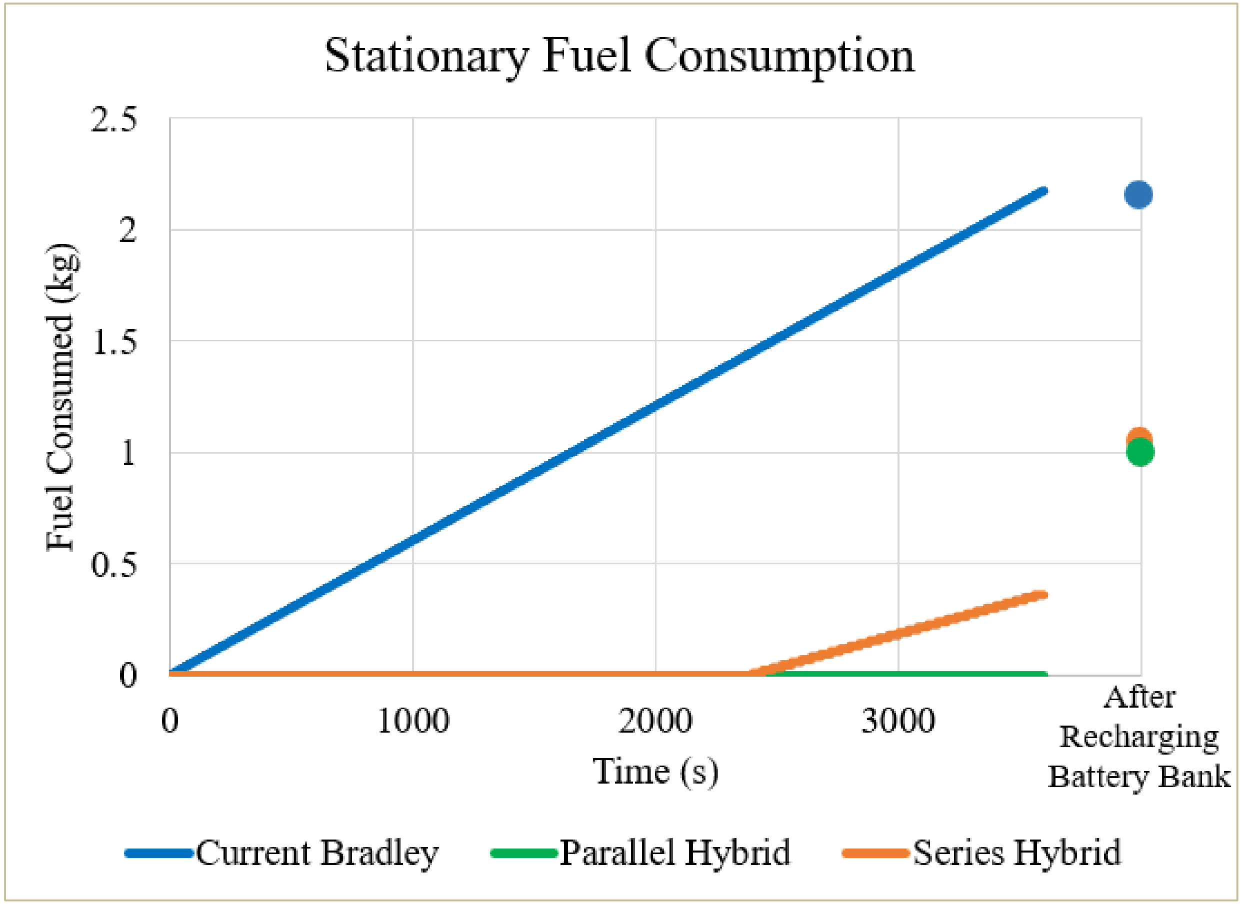
Velocity profile for highway drive cycle



Velocity profile and grade for off-road drive cycle

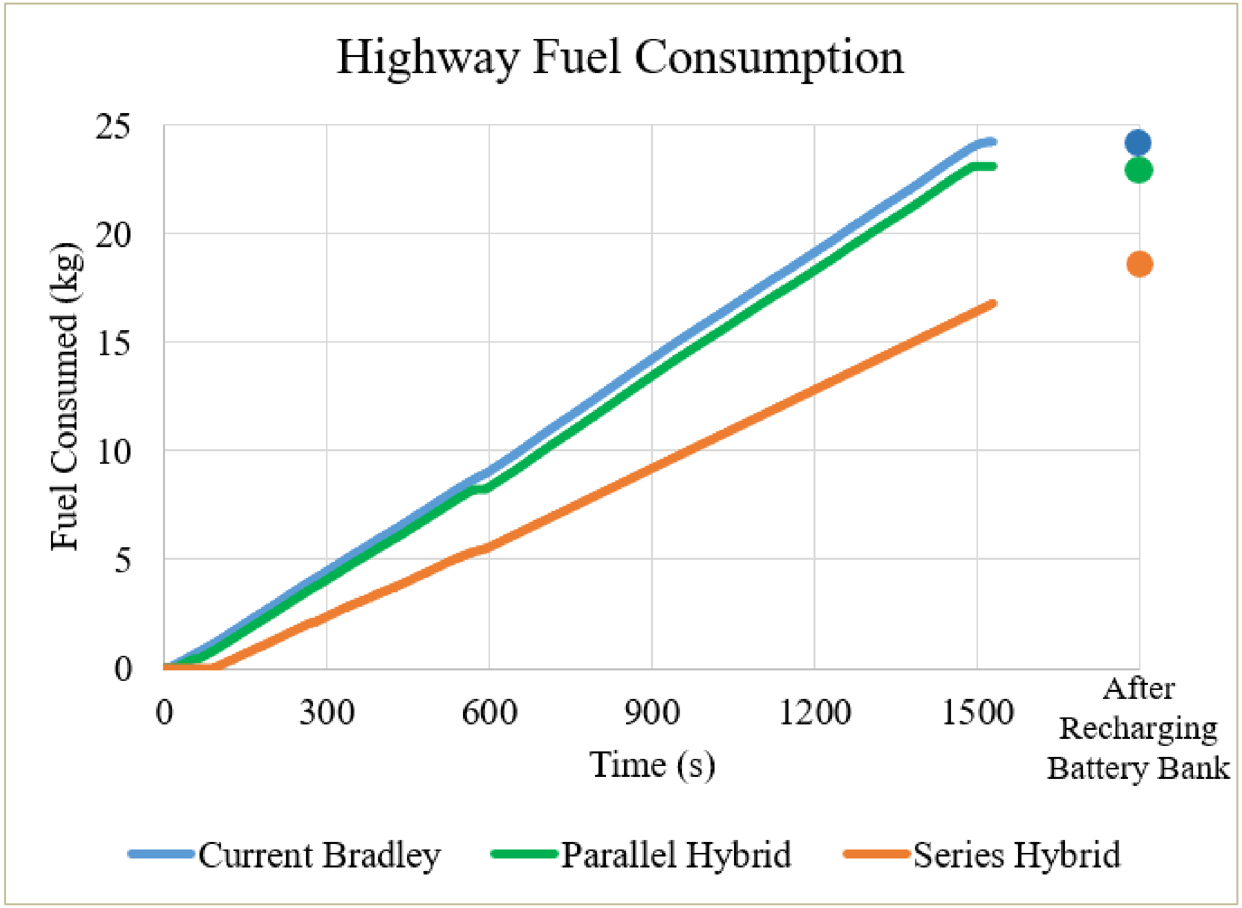


Drive Cycle Analysis - Results



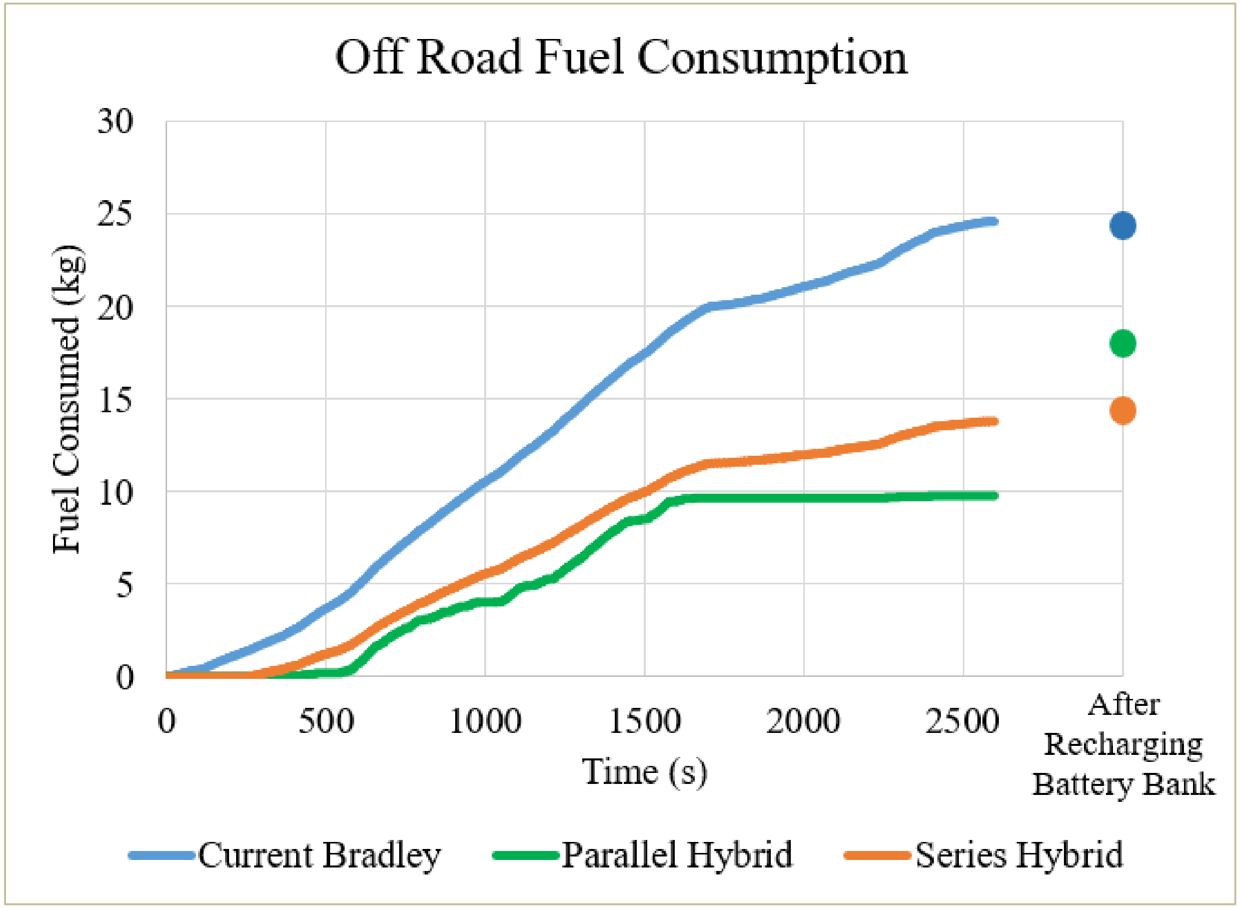
- For current system, engine is running at idling condition (low η)
- For hybrid vehicles, batteries can be recharged by engines running at optimal condition.

Drive Cycle Analysis - Results



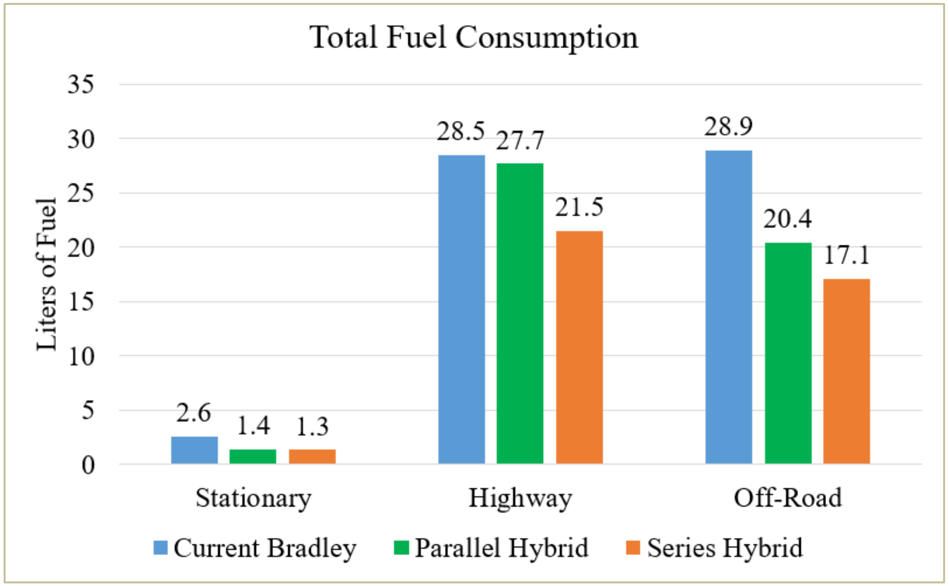
- For hybridized systems, parallel configuration performs somewhat similar to current BFV.
- Series hybrid provides a reduction in fuel consumption.

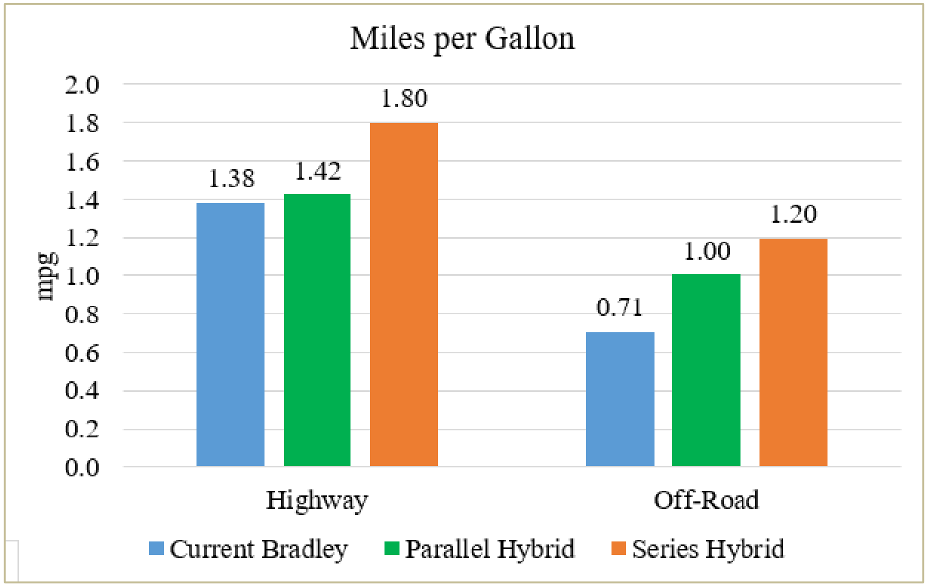
Drive Cycle Analysis - Results



- For off-road conditions, vehicle is moving slowly with significant braking, resulting in large benefits for hybrid vehicles.

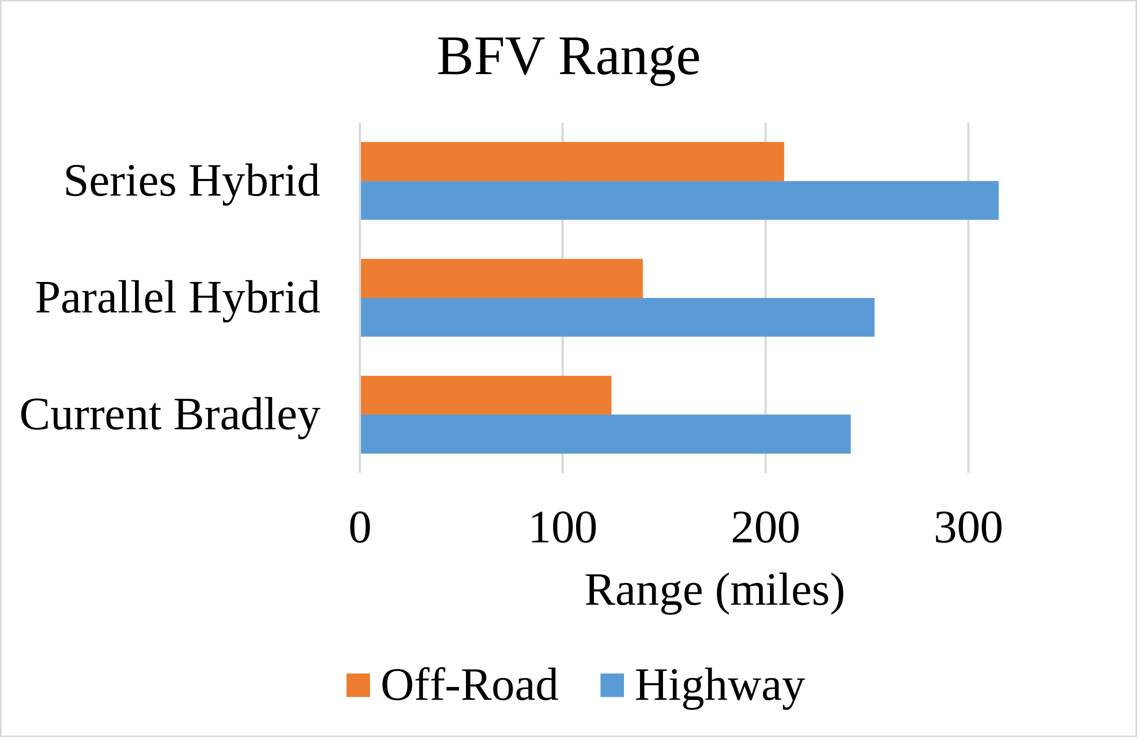
Drive Cycle Analysis - Results





- Despite increased weight, hybrid systems saw a decrease in fuel consumption for all three drive-cycles.
- Series provides larger benefit than parallel hybrid system.

Range Benefits



- Keeping the same 175-gallon fuel tank, the increased fuel efficiency with hybrid options would increase the range of the vehicles

Hybrid Challenges

- Steering
- Volume constraints
- Volatility of batteries
- Security
- Environmental issues

Conclusions

- Analysis presented a simple drive-cycle model for BFV using series and parallel hybrid architectures

- Series Architecture provided significant benefits:
  - Highway fuel consumption reduced by 24%
  - Off-road fuel consumption reduced by 40%
  - Extended range by 30% on the highway, and 67% off-road

- Significant challenges remain, but hybridization of Bradley Fighting Vehicle could provide large amount of value to the Army.

Questions?