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# PLUG-IN VEHICLE CONTROL STRATEGY: FROM GLOBAL OPTIMIZATION TO REAL-TIME APPLICATION

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FreedomCAR & Fuel Partnership

U.S. Department of Energy

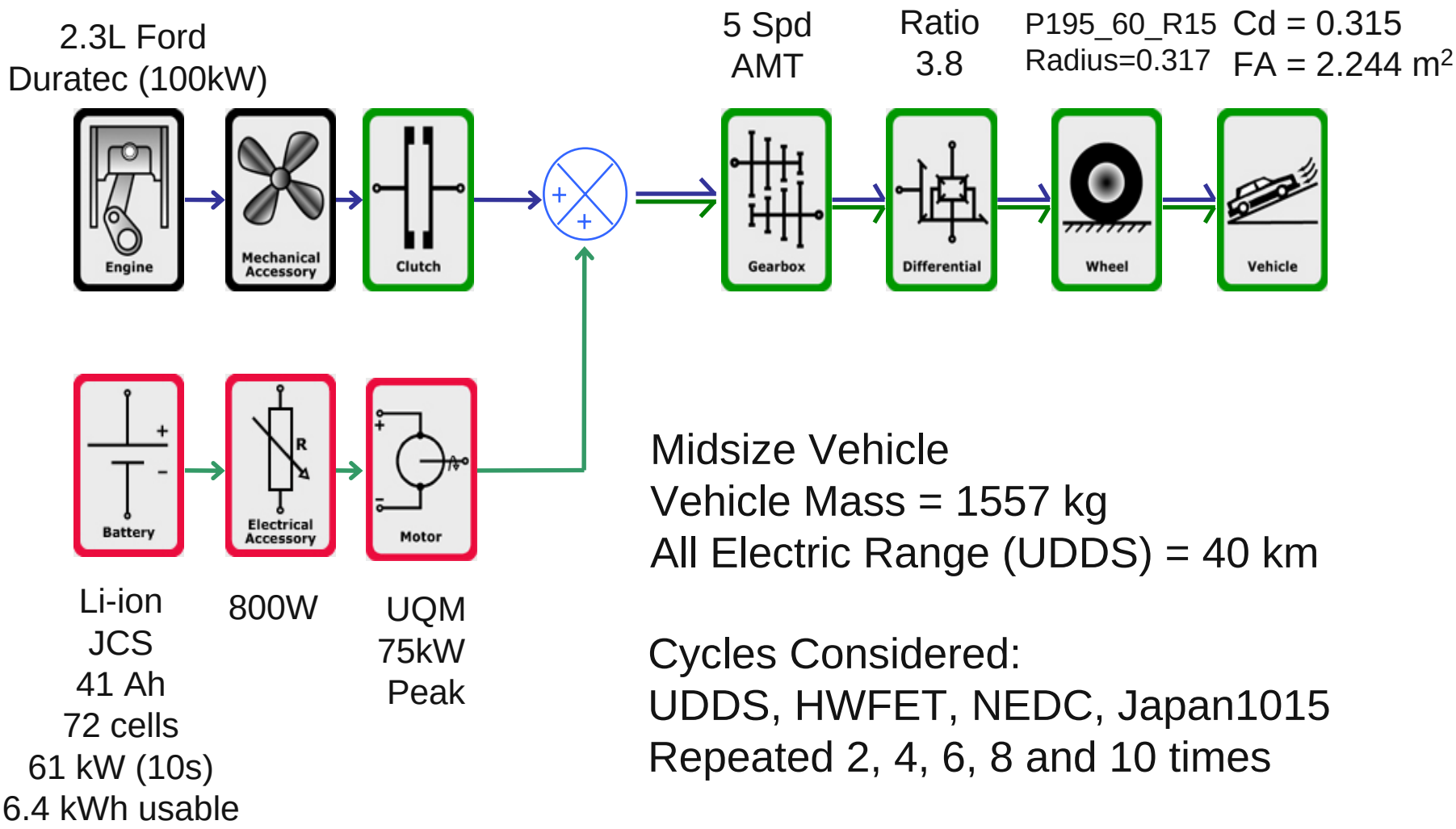
THE UNIVERSITY OF CHICAGO

A U.S. Department of Energy laboratory managed by The University of Chicago

# OUTLINE

- Vehicle Assumptions
- Control Strategy Development Process
- Optimization Results
- Comparison with Other Controls
- Conclusion & Next Steps

# Vehicle Assumptions




Midsize Vehicle
Vehicle Mass = 1557 kg
All Electric Range (UDDS) = 40 km

Cycles Considered:
UDDS, HWFET, NEDC, Japan1015
Repeated 2, 4, 6, 8 and 10 times

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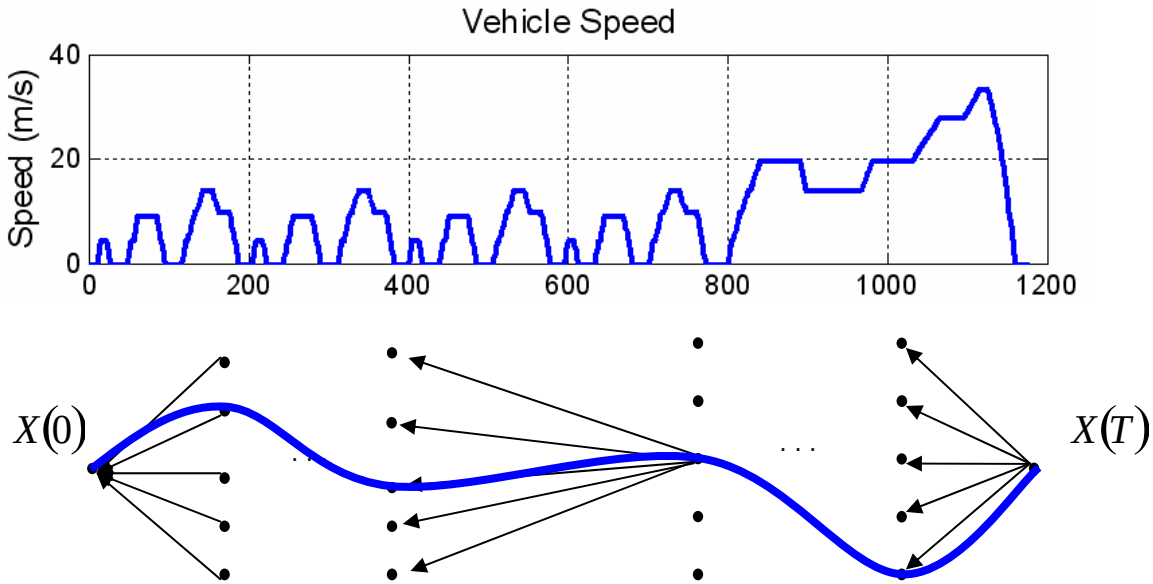
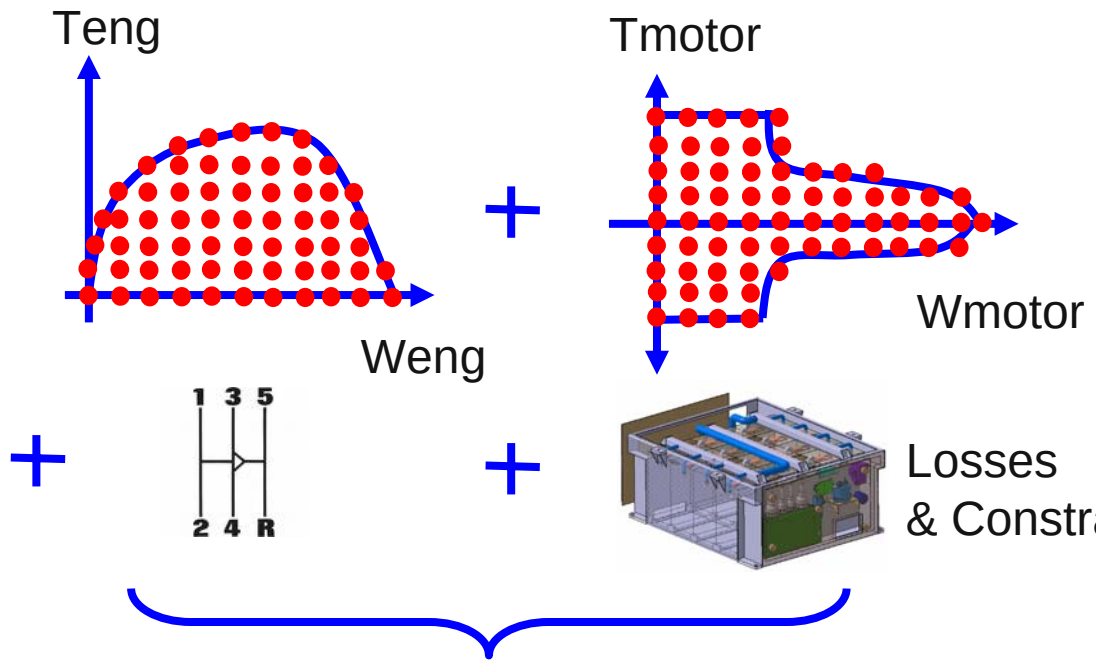
# Global Optimization Definition

- Knowing the drive cycle, what would be the optimum component operating points minimizing powertrain losses?
- Use Bellman principle: *"a sequence of decisions is optimal if, for any state and time, the following decisions are an optimal sequence of decisions for the corresponding problem having these state and time as initial conditions"*



# Methodology

Global Optimization



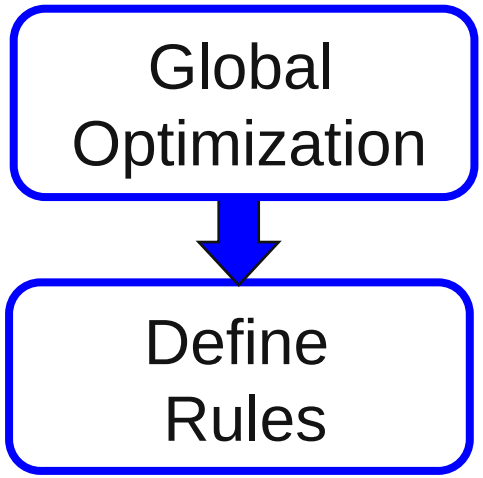

$$\{P_0(t+1), SOC_{0'}(t+1)\}, J_{0,0'}(t)$$

$$X(0) \quad \{P_m(t), SOC_n(t)\} \quad U_0(t) \quad U_M(t) \quad X(T)$$

$$\{P_M(t+1), SOC_{M'}(t+1)\}, J_{M,M'}(t)$$

Engine Torque, Motor Torque, SOC, Gear Ratio

# Methodology




Parameters tuned to be close to the optimum

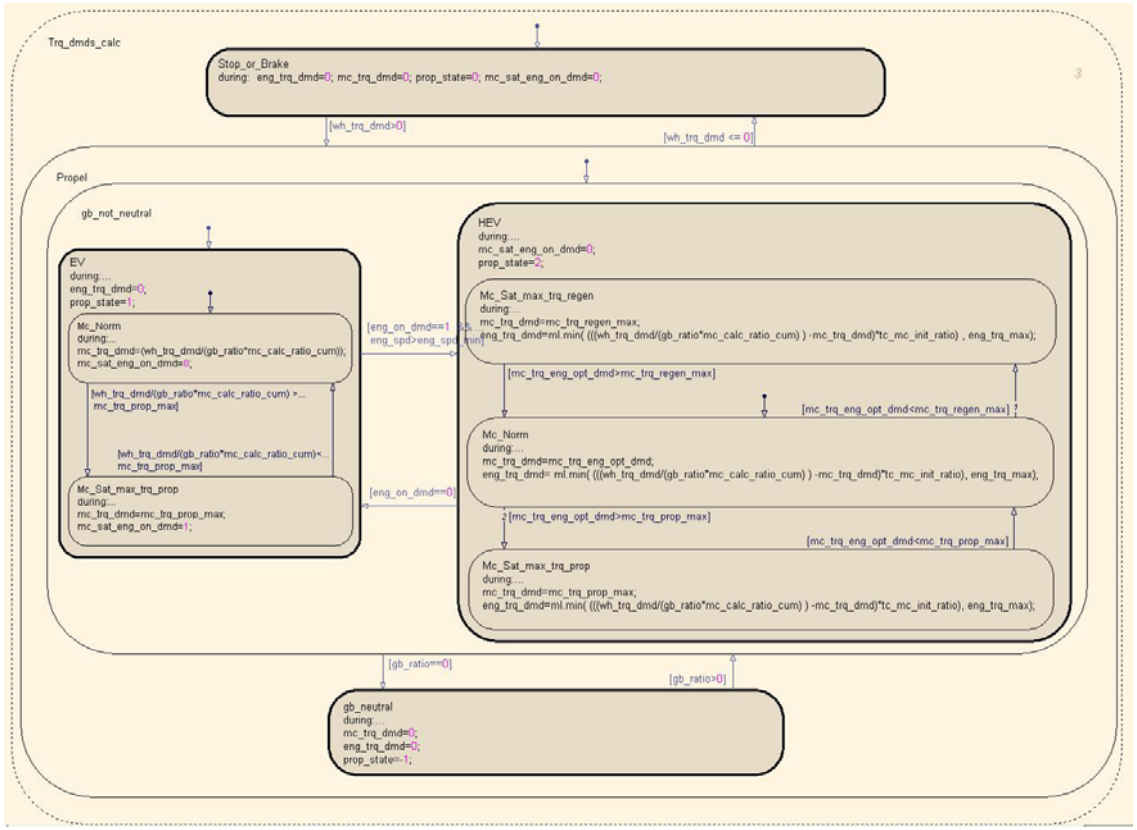
If Engine ON
    Engine Torque = Function (Parameters)
    Motor provides complement
else
    Motor provides the power
end

# Methodology

Global Optimization

Define Rules

Develop Control



# Methodology

Global Optimization

↓

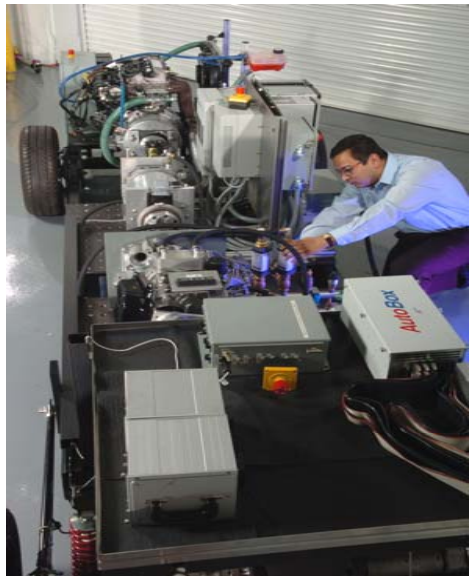
Define Rules

↓

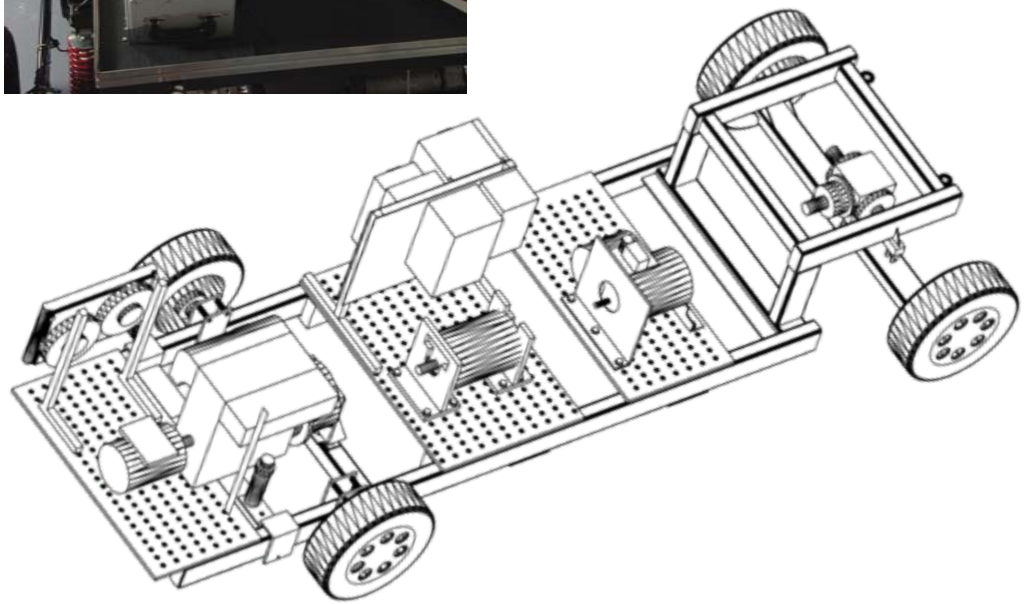
Develop Control

↓

Implement Control




MATT:
Mobile
Advanced
Technology
Test bed



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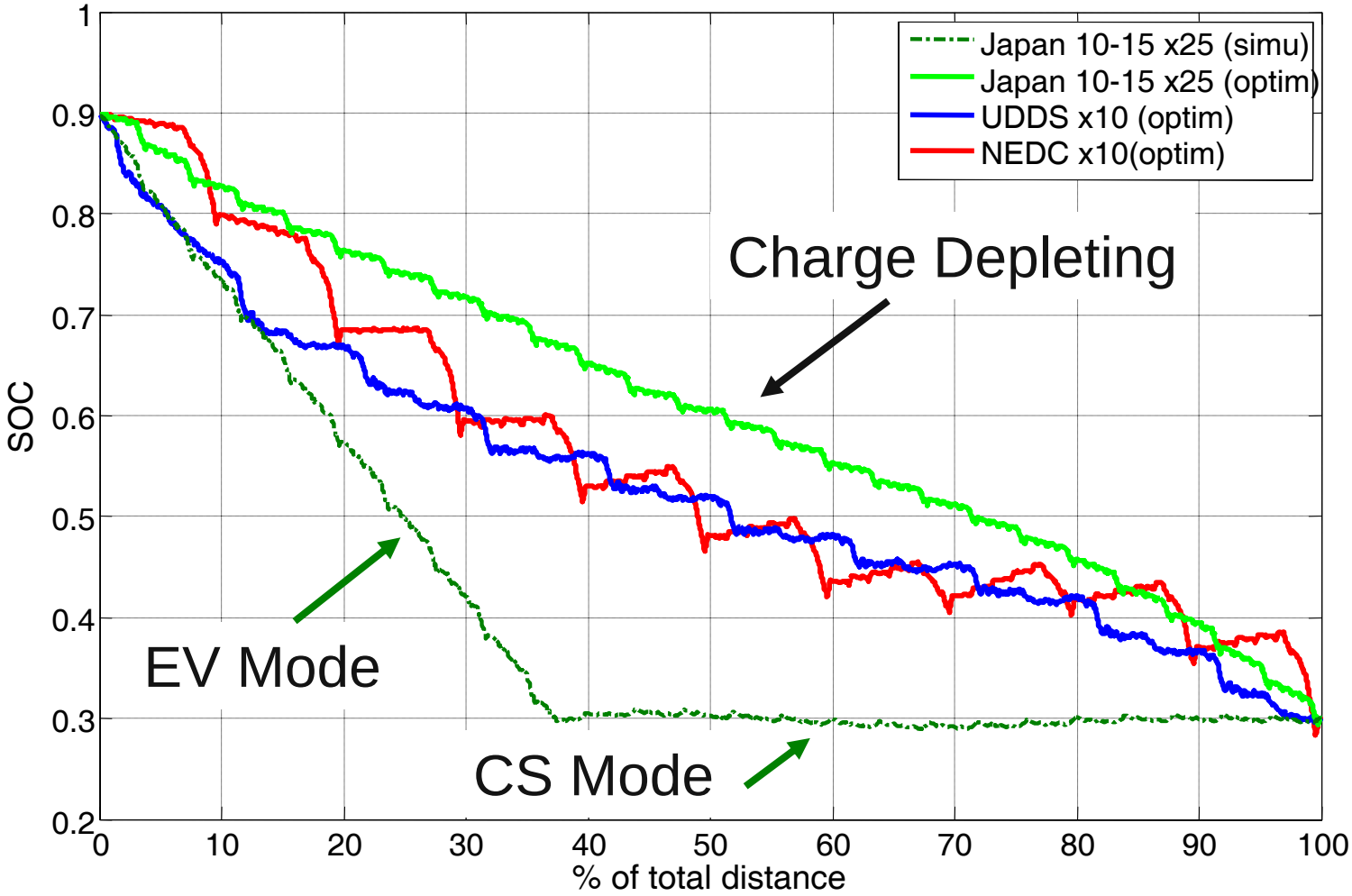
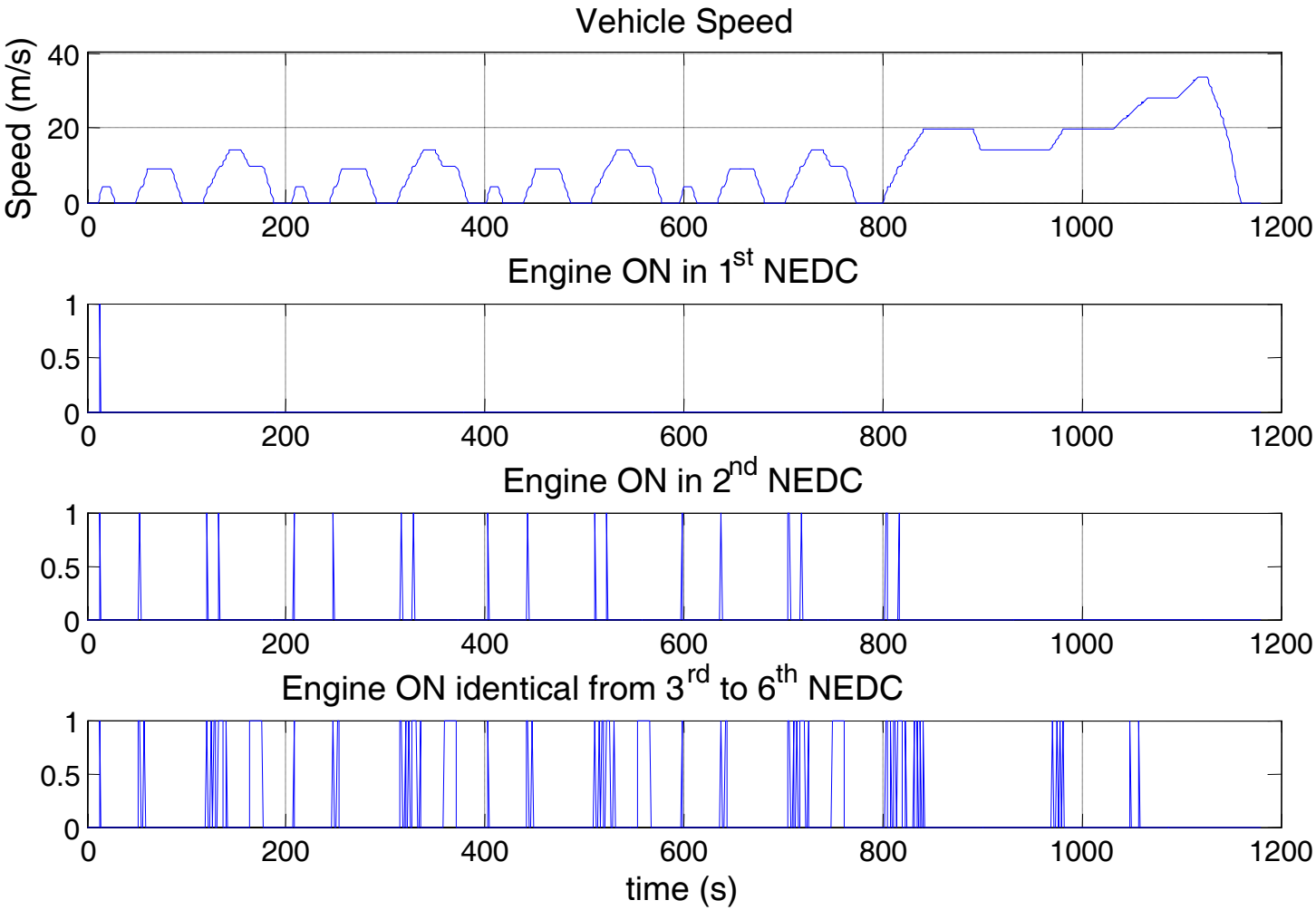
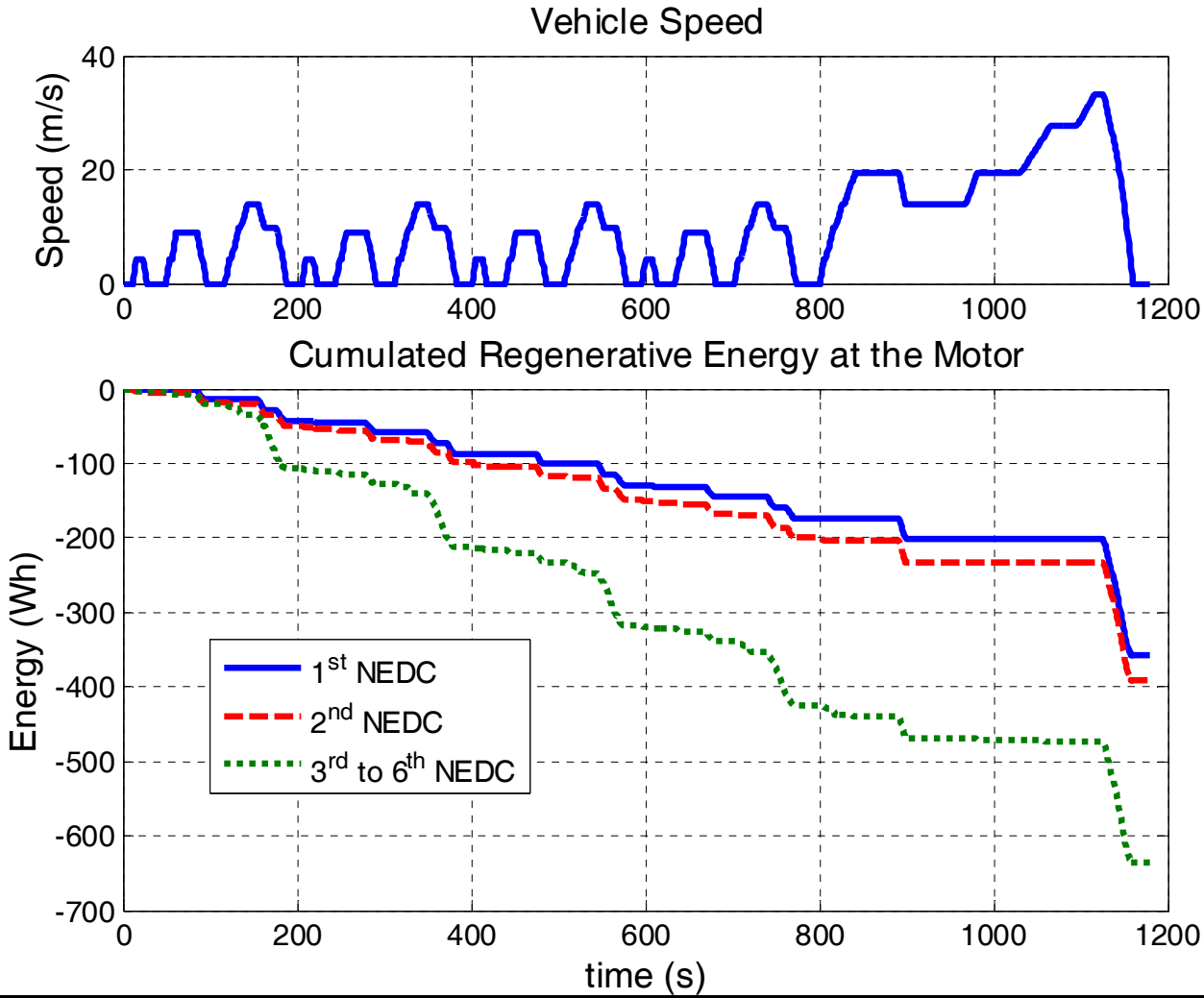
# Engine Should be Used Throughout the Trip



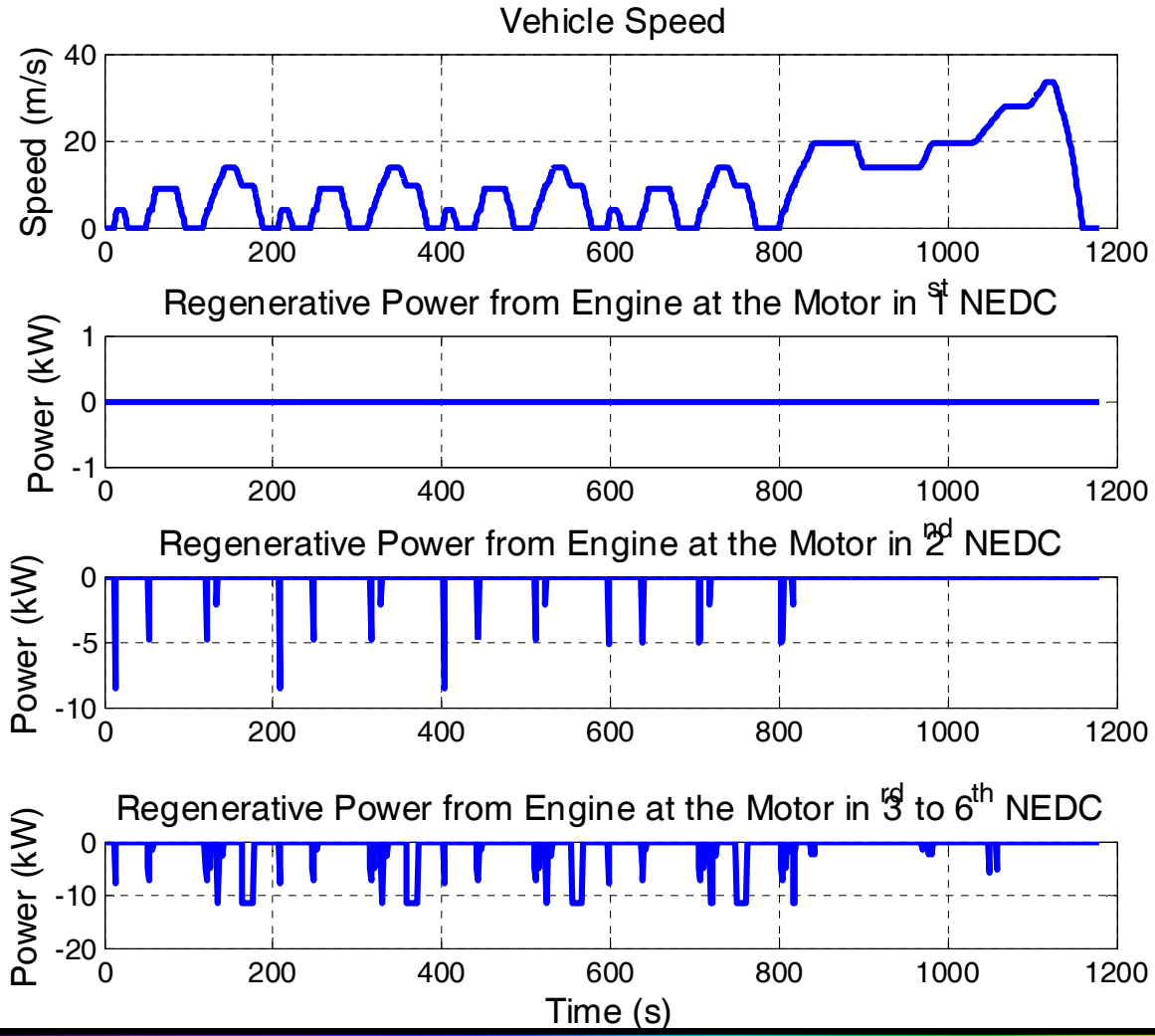
# Engine ON Depends on Battery SOC



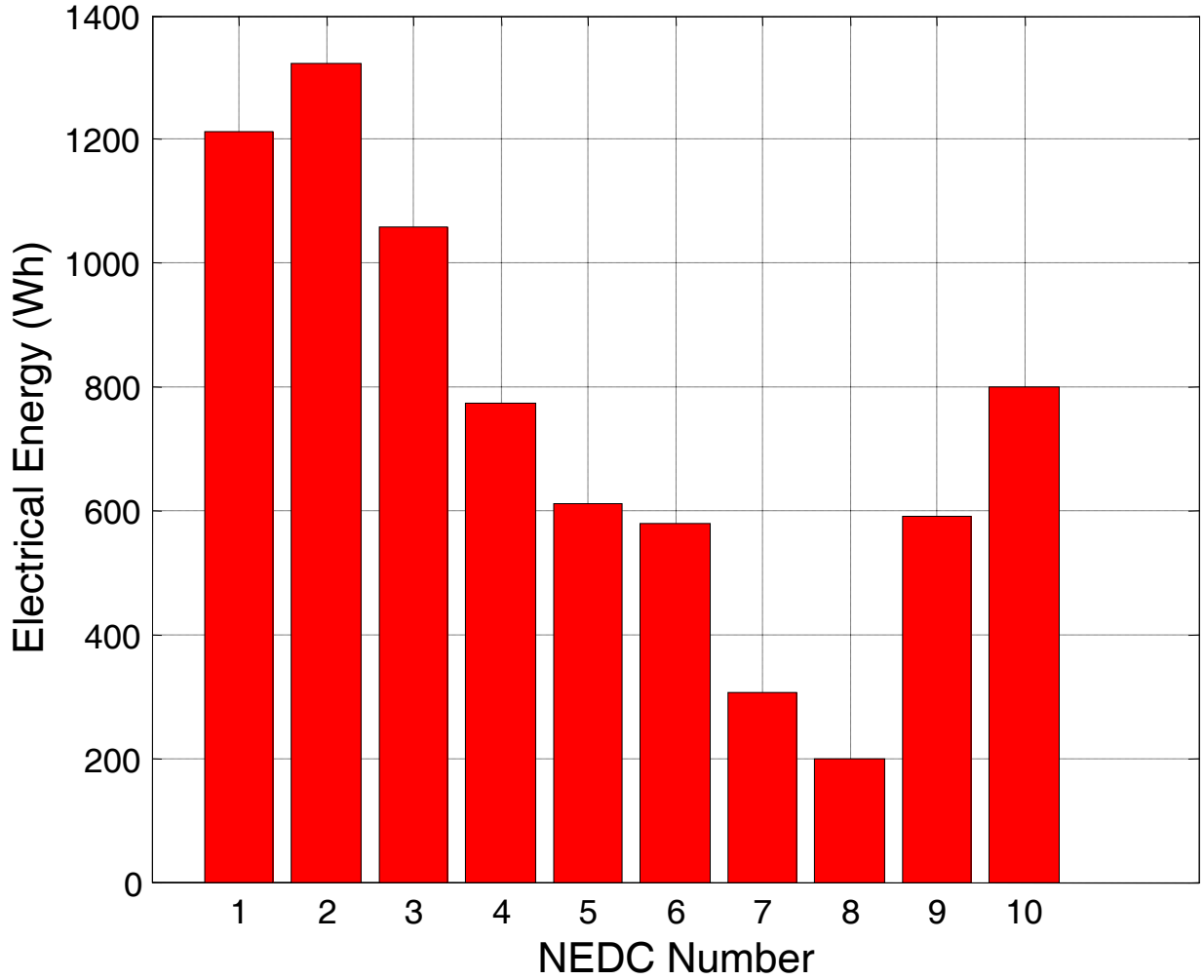
# Engine ON Identical Once Maximum Regenerative Braking is Achieved



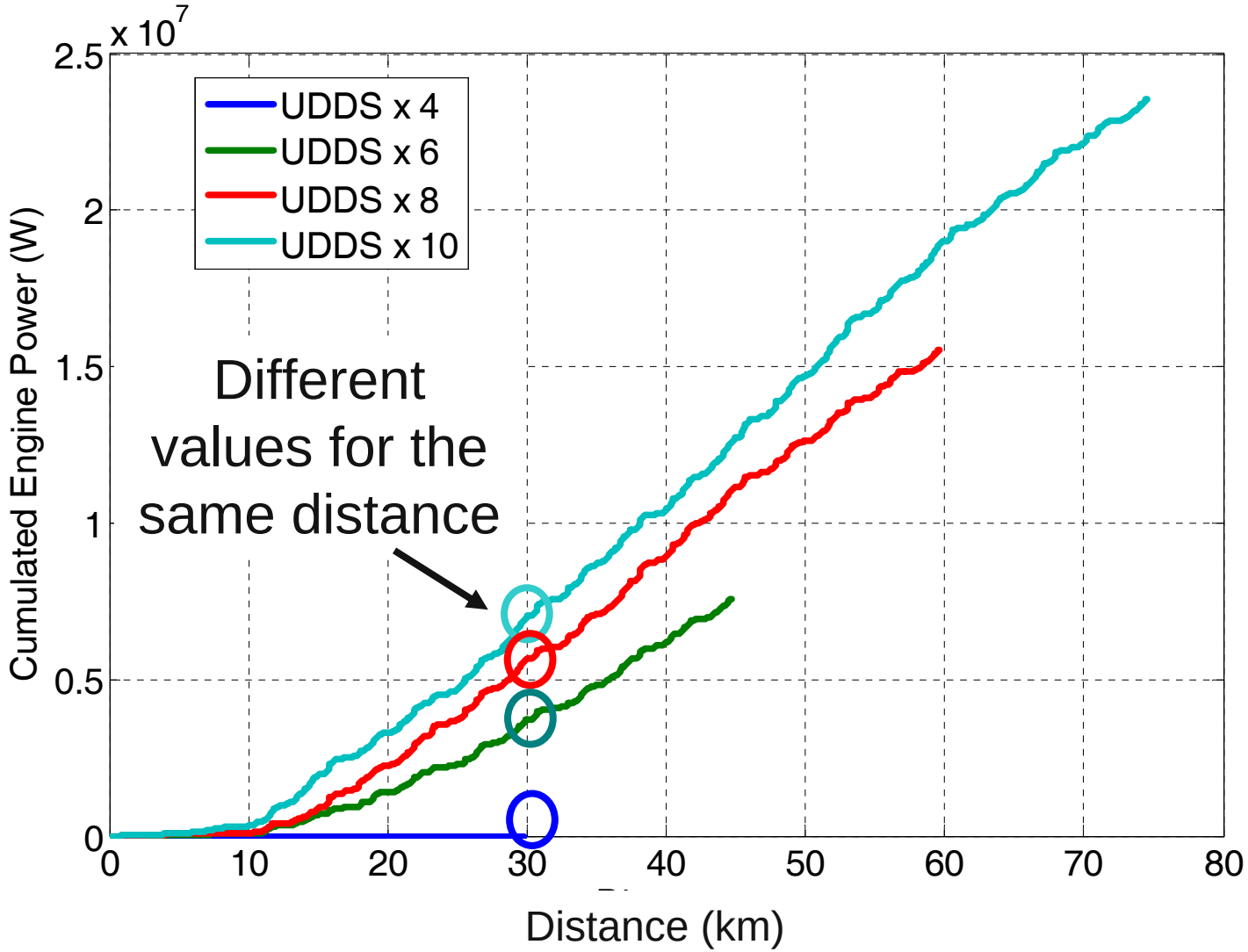
# Even if We Deplete the Battery, the Engine is Used to Recharge it Throughout the Trip



# The Minimum SOC is Only Achieved at the End of the Trip



# Optimum Control Depends on the Distance



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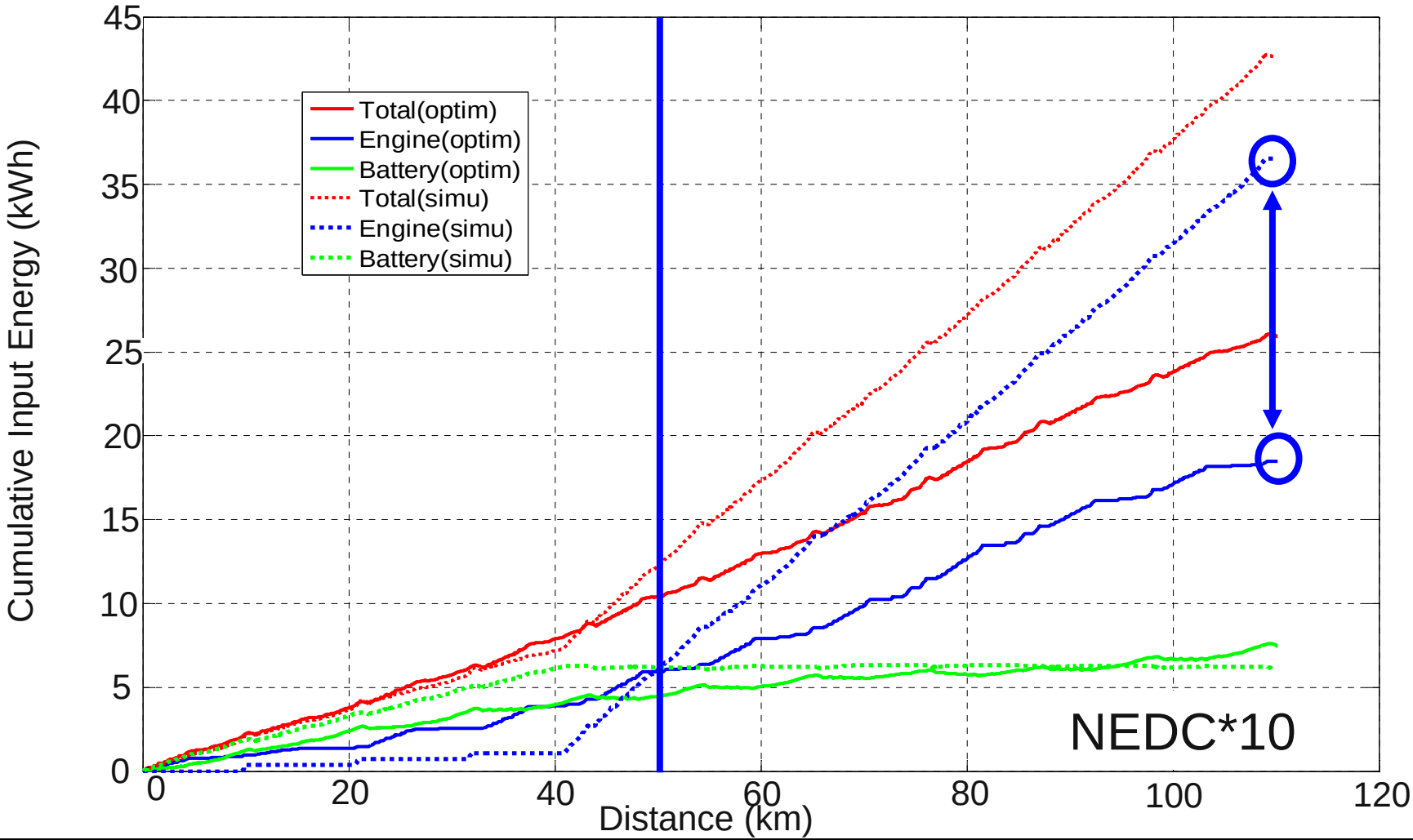
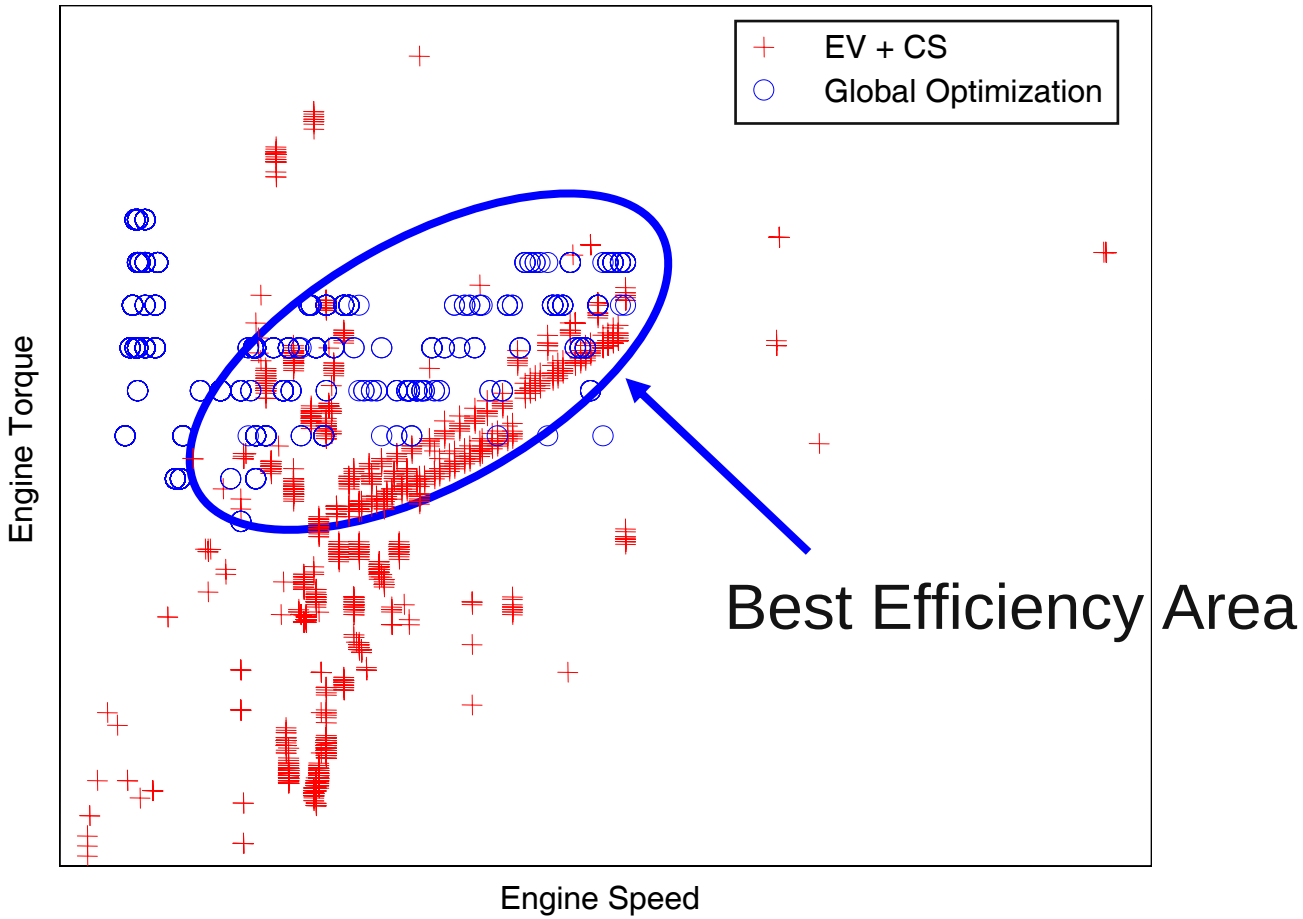
# Different Charge Depleting Controls Lead to Significant Differences in Engine Energy Consumption



# Energy Difference Mostly Due to Engine Operating Conditions



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# *Distance is Key to PHEV Control*

- For HEVs, the optimum control strategy depends on driving cycles and SOC.
- For PHEVs, it also depends on the distance and the All Electric Range (AER). Vehicle Miles Traveled (VMT) distribution should be taken into account.
- For trip distance under AER, the EV mode is the most appropriate.
- For trip distance above AER:
  - For large AER, EV mode + Charge Sustaining appears to be the most appropriate option
  - For small AER, Charge Depleting is more appropriate

# *Key Control Strategy Rules*

- The battery should be used in priority until the maximum regenerative energy can be achieved.
- The lowest SOC should only be used towards the end of the trip to minimize the losses.
- Engine should be used close to its best efficiency curve.
  - Operating above minimum SOC provides more flexibility for this control.
  - The battery can be charged if overall powertrain efficiency improved

# Next Steps

- Knowing the trip, develop real-time control strategy
- Not knowing the trip, develop adaptive real-time control strategy
- Test the control strategy in battery Hardware-In-the-Loop
- Evaluate the impact of emissions on control strategy using MATT