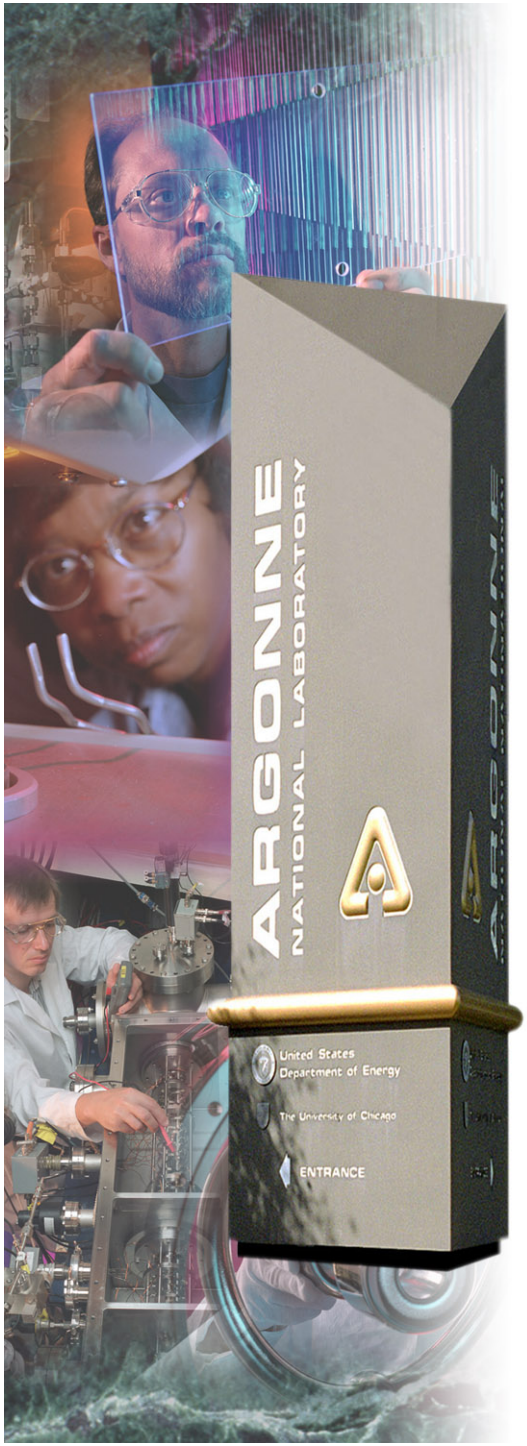


# Trade-Offs Between Fuel Economy and NOx Emissions Using Fuzzy Logic Control With a Hybrid CVT Configuration

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Sponsored by B. Kost
U.S. Department of Energy

***Argonne National Laboratory***

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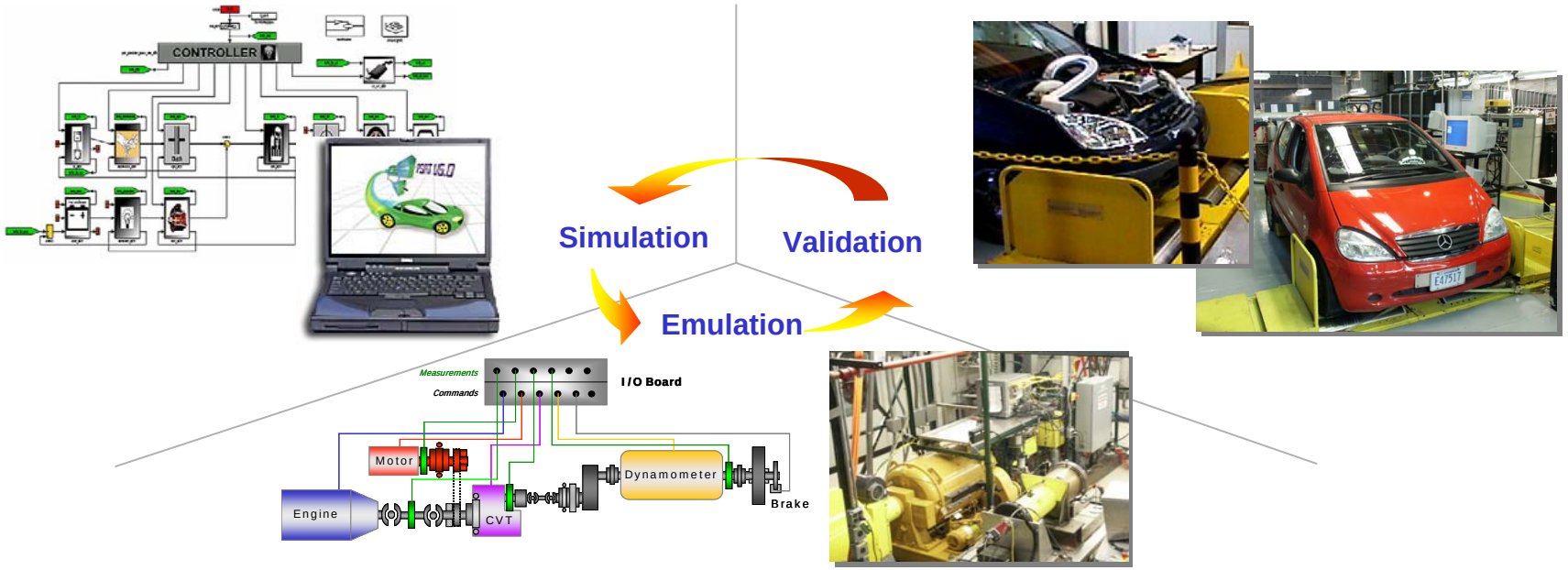
# Tools for Integrated Development




- **Component/subsystem models used in vehicle simulation must be applicable to emulated and real vehicle environments**
  - Forward models for realistic behavior
  - Comparable inputs/outputs to hardware
  - Validation is critical

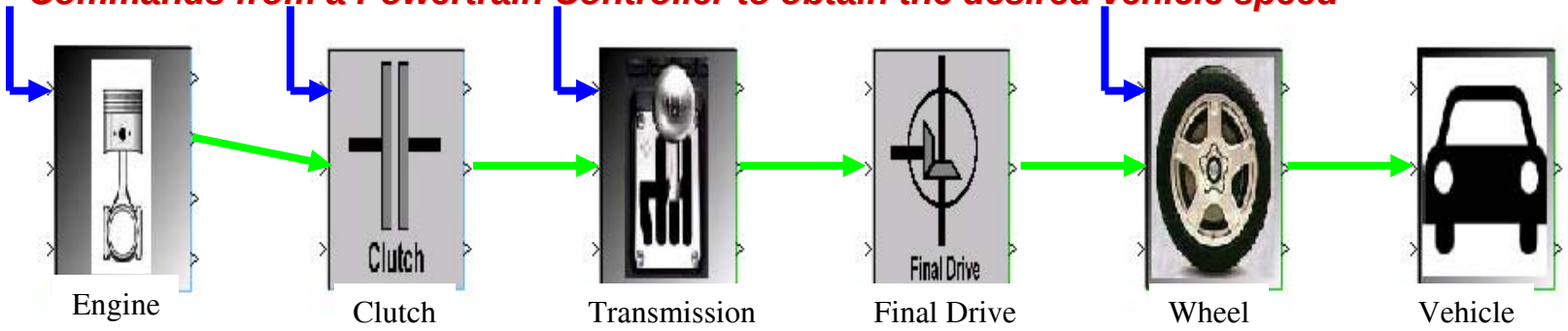
# *PSAT Is Flexible & Reusable*

- **Drivetrains constructed from user choices**
- **Numerous configurations can be explored(>130: conventional, electric, fuel cell, parallel, series, power split...)**
- **User-friendly graphical user interface**
- **Easy integration of new component data, models and control**
- **Model format is generic (3 inputs / 3 outputs)**

# PSAT Looks Forward

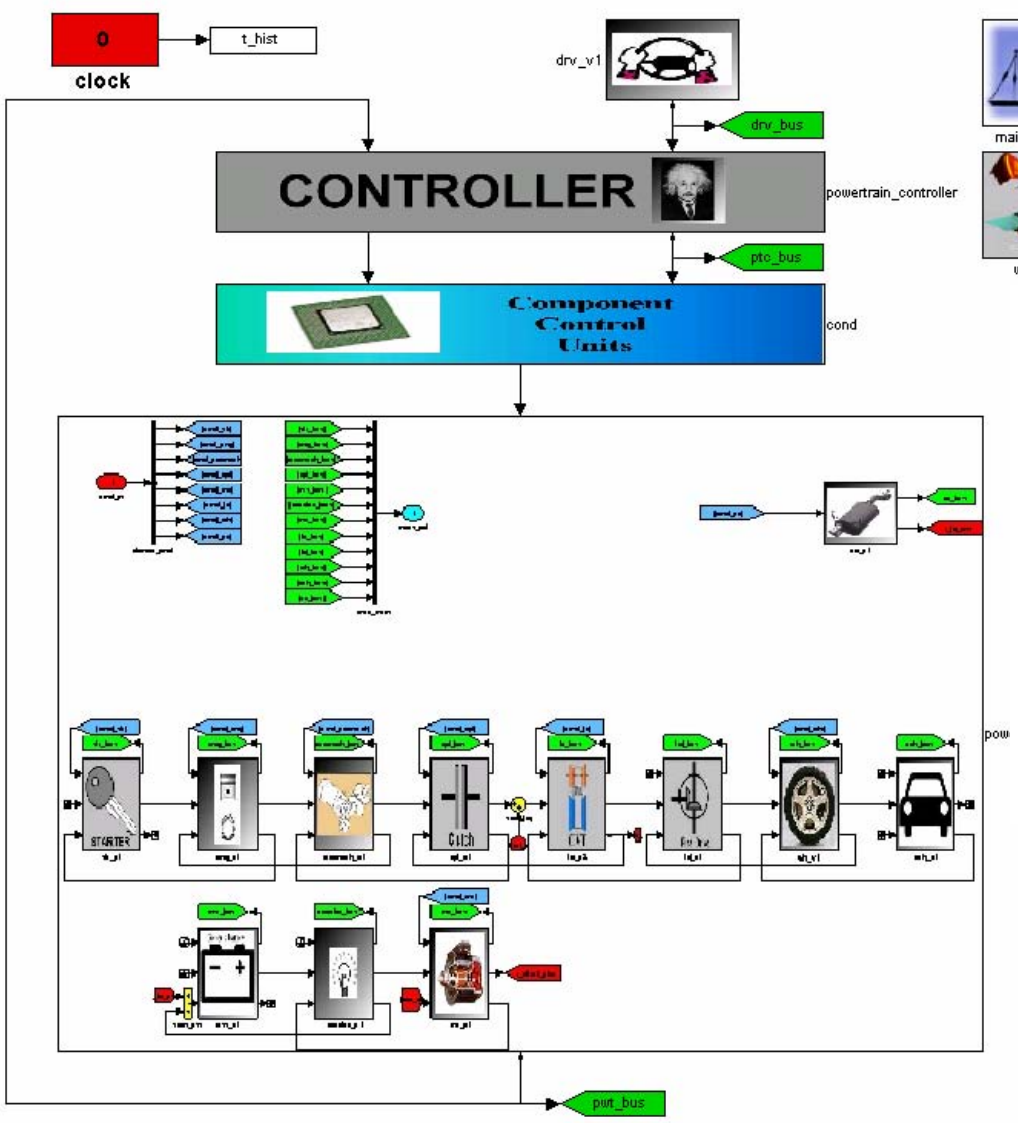
Forward modeling (driver-to-wheels) more realistically predicts system dynamics, transient component behavior and vehicle response.

***Commands from a Powertrain Controller to obtain the desired vehicle speed***




- More accurately represents component dynamics (e.g. engine starting and warm-up, shifting, clutch engagement ...)
- Allows for advanced (e.g. physiological) component models
- Allows for the development of control strategies that can be utilized in hardware-in-the-loop or vehicle testing
- Small time steps enhance accuracy

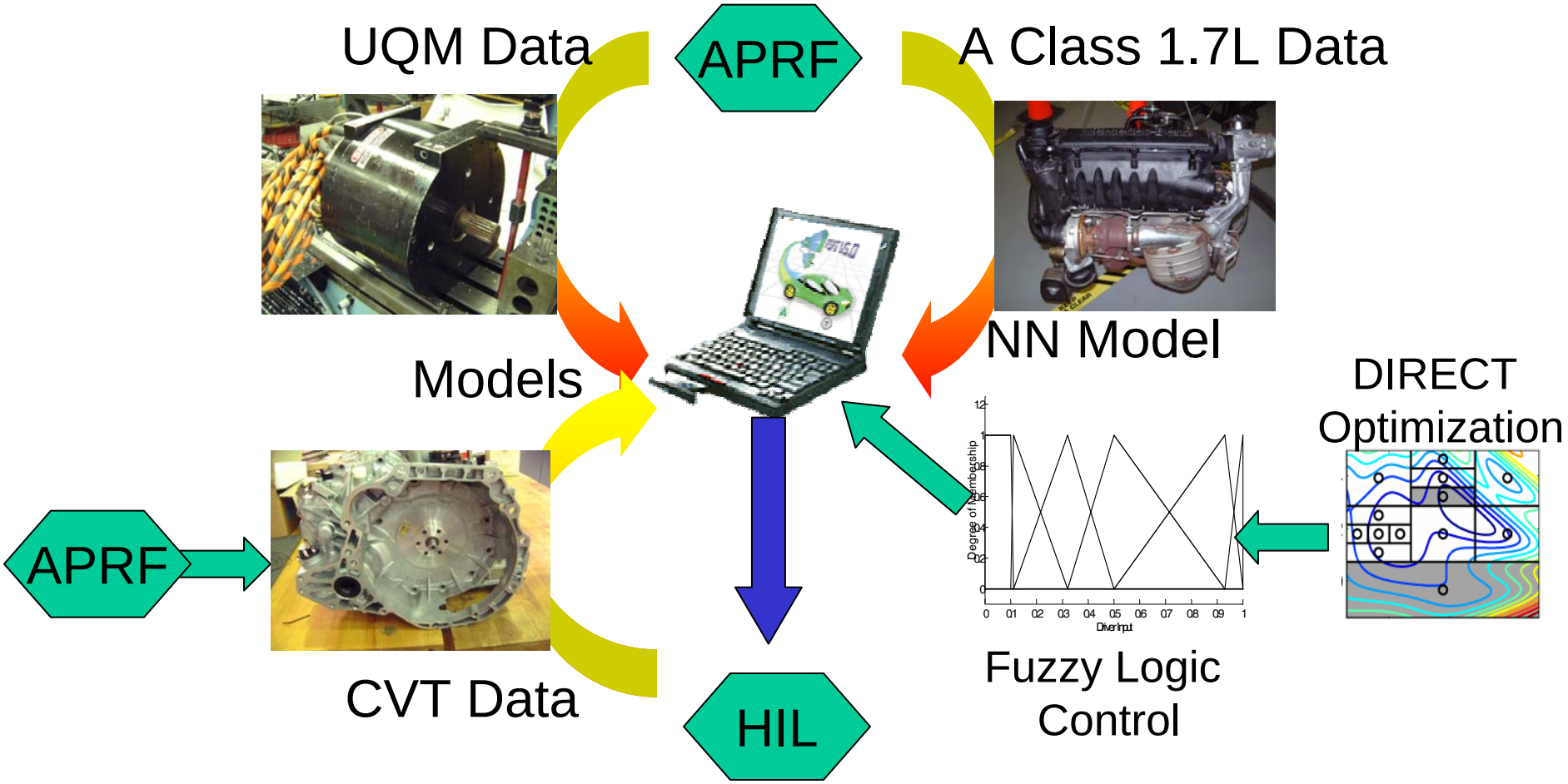
# Vehicle Characteristics Summary




Pre-transmission parallel HEV:

| | |
|---|---|
| Vehicle Mass | 1297kg |
| FA | 1.5 m2 |
| Cd | 0.2 |
| Engine | 1.7L MB CIDI |
| Motor | 32kW PM UQM |
| CVT | JATCO CK2-CVT |
| Battery | Li-ion 14Ah 96 cells |

# *Trade-off Between Fuel Economy and Emissions*



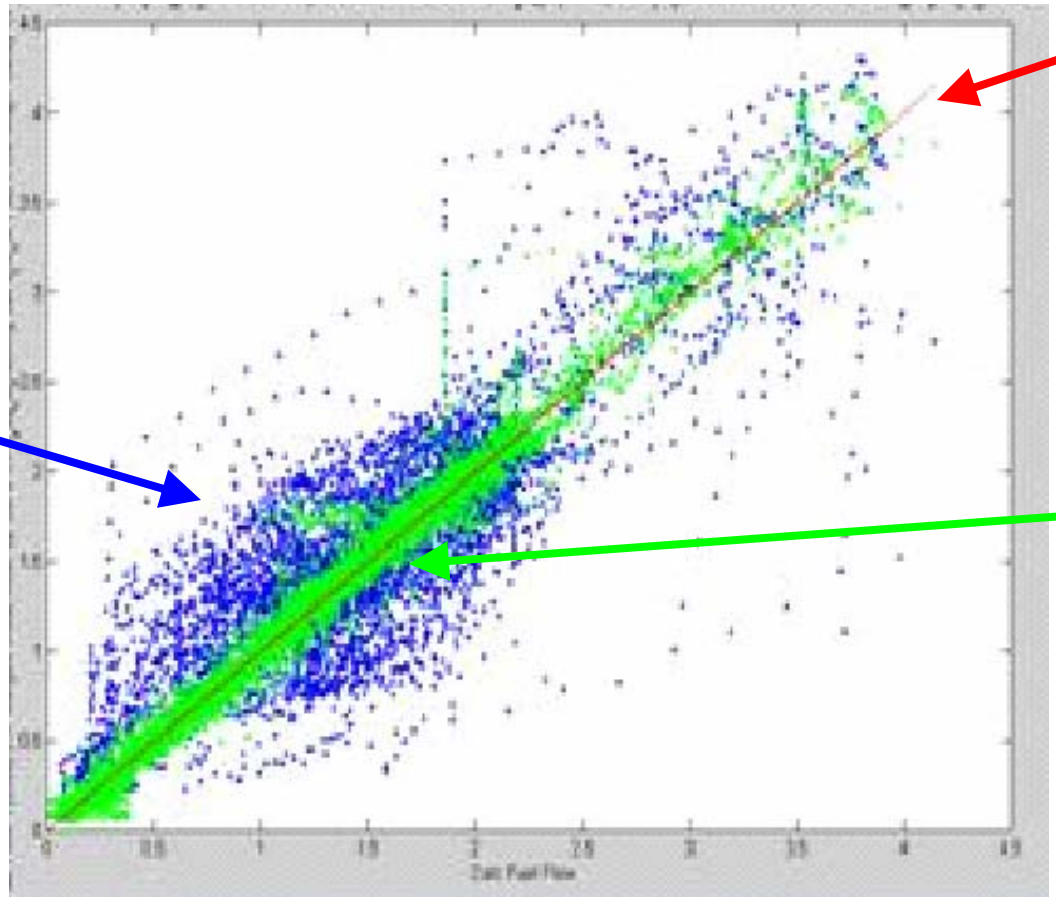
# *State-of-the-art Test Facility Used For Engine Testing*

Dynamometer capability:
Highly transient
220 kW, 1067 Nm, 8000 rpm
Inertia 1.5 kg-m^2

**Emission Equipments.**

- **Pierburg AMA-2000 raw bench**
- **Cambustion fast HC and NO**
  - Two channels per species
  - Less than 5 msec response time
- **TEOM (Tapered Element Oscillating Microbalance)**

# *NN NOx Emission Demonstrates Better Correlation*

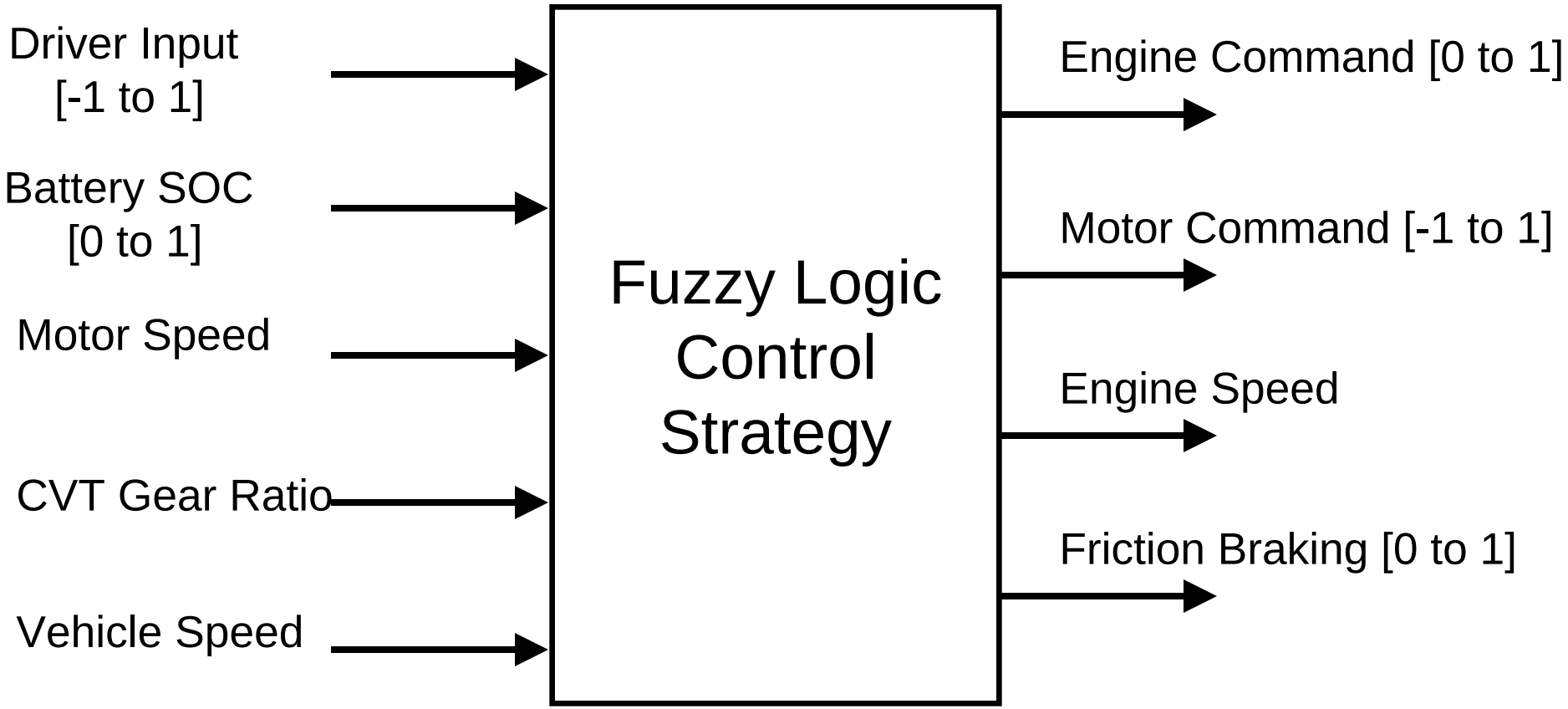


Test data

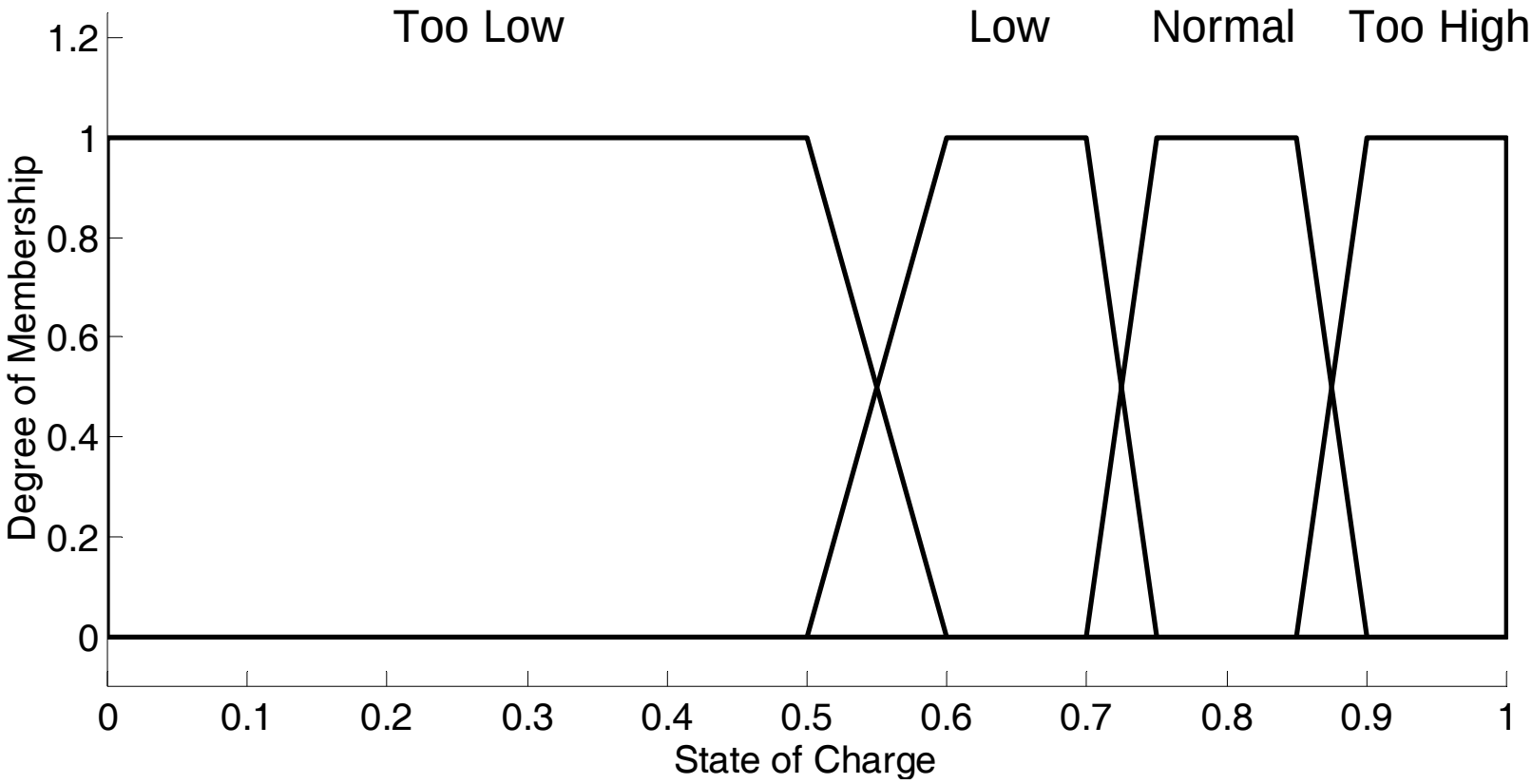
Steady state

Neural Network

# *Fuzzy Logic Controller Overview*



# *Membership Function For Battery State of Charge*



# *Strategy Defined By 27 Rules*

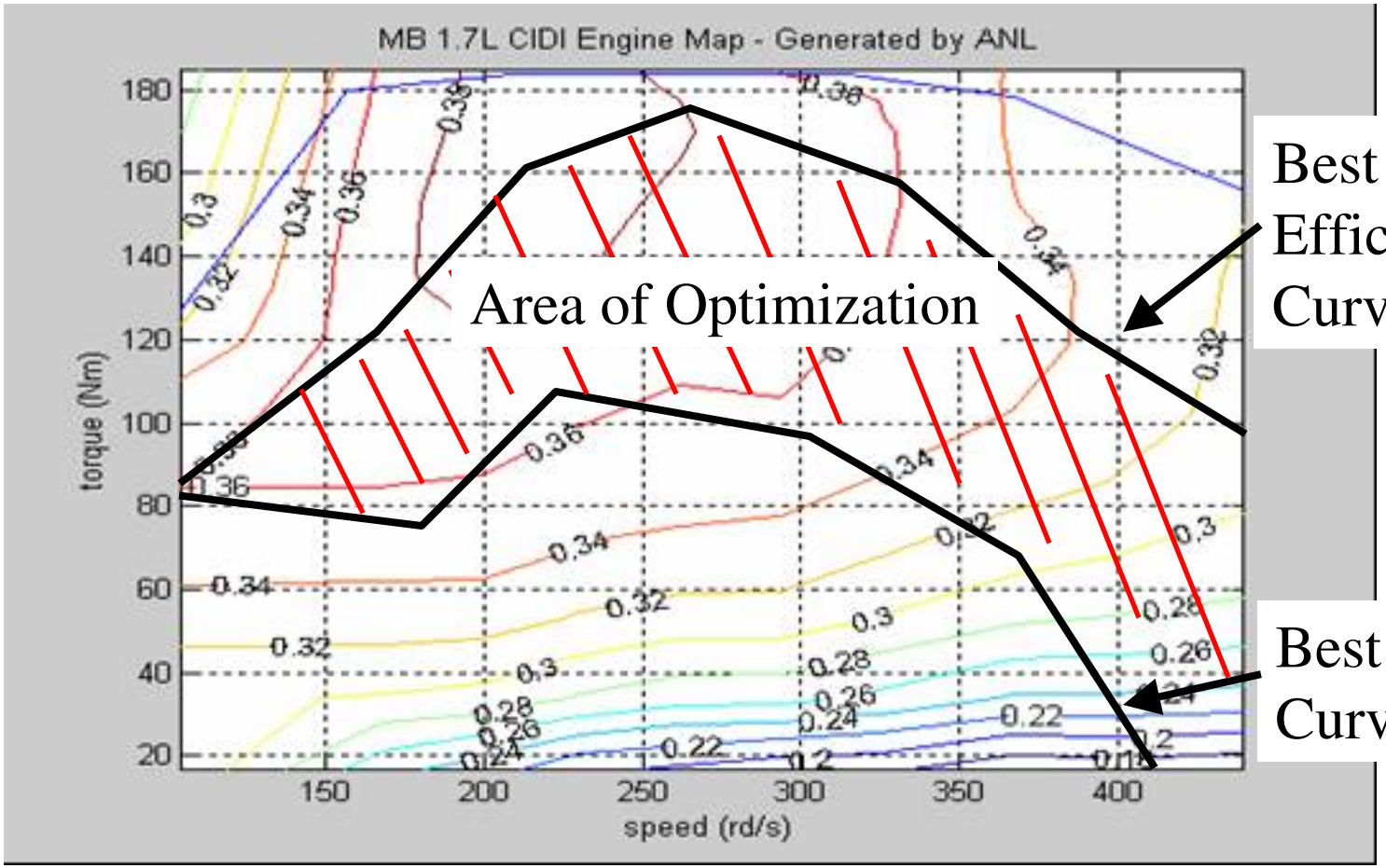
***If* driver input demand is medium *and***
**SOC is normal *and***
**Motor speed is optimal *and***
**CVT gear ratio is not the largest *and***
**vehicle speed is not low**
***Then* Engine speed is 375 rad/s *and***
**Engine command is 0.76* *and***
**Motor command is –0.25**

Control inputs are used to define the condition

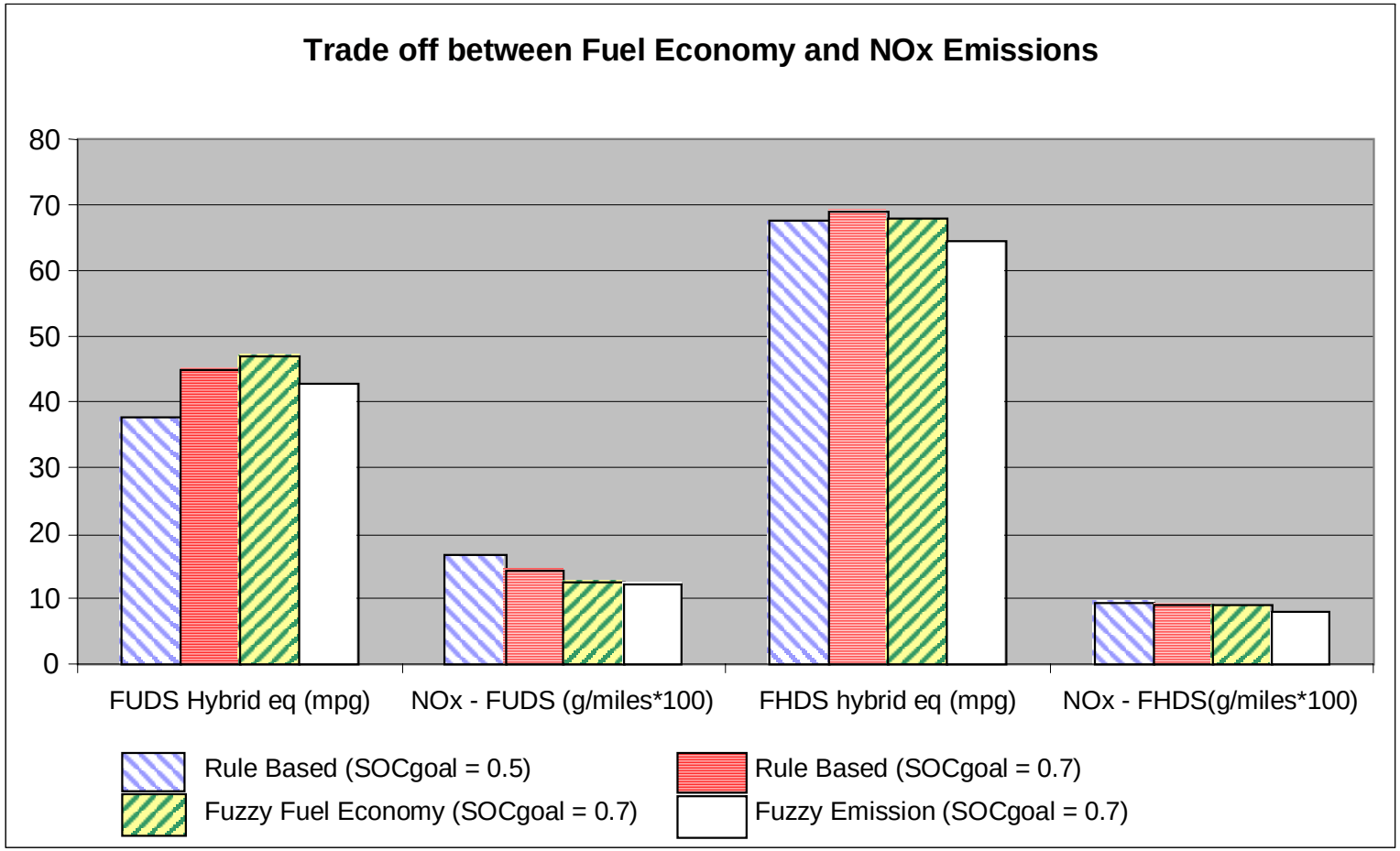
Outputs are defined

*** Means we ask for 76% of the best efficiency curve**

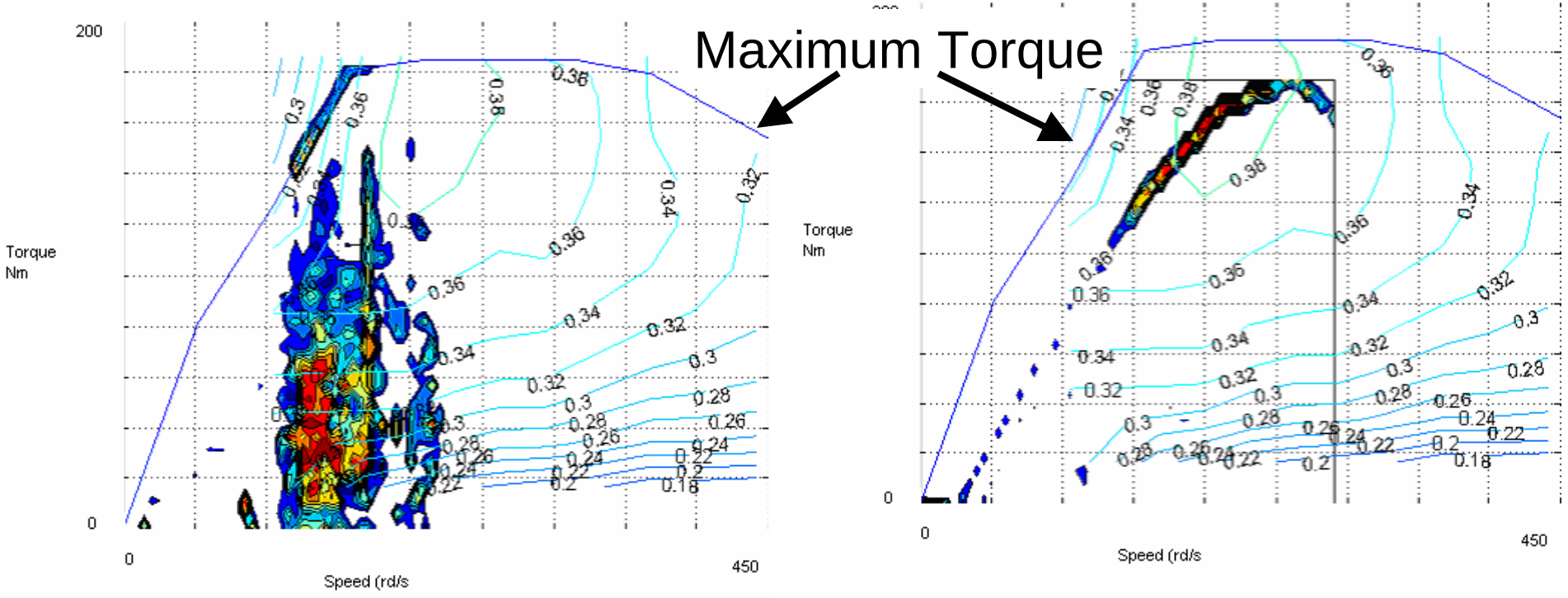
# *Fuel Economy vs. NOx Emission Control Strategy*



# *FE and NOx Can Vary From +/- 10% Based Upon Control Strategy*



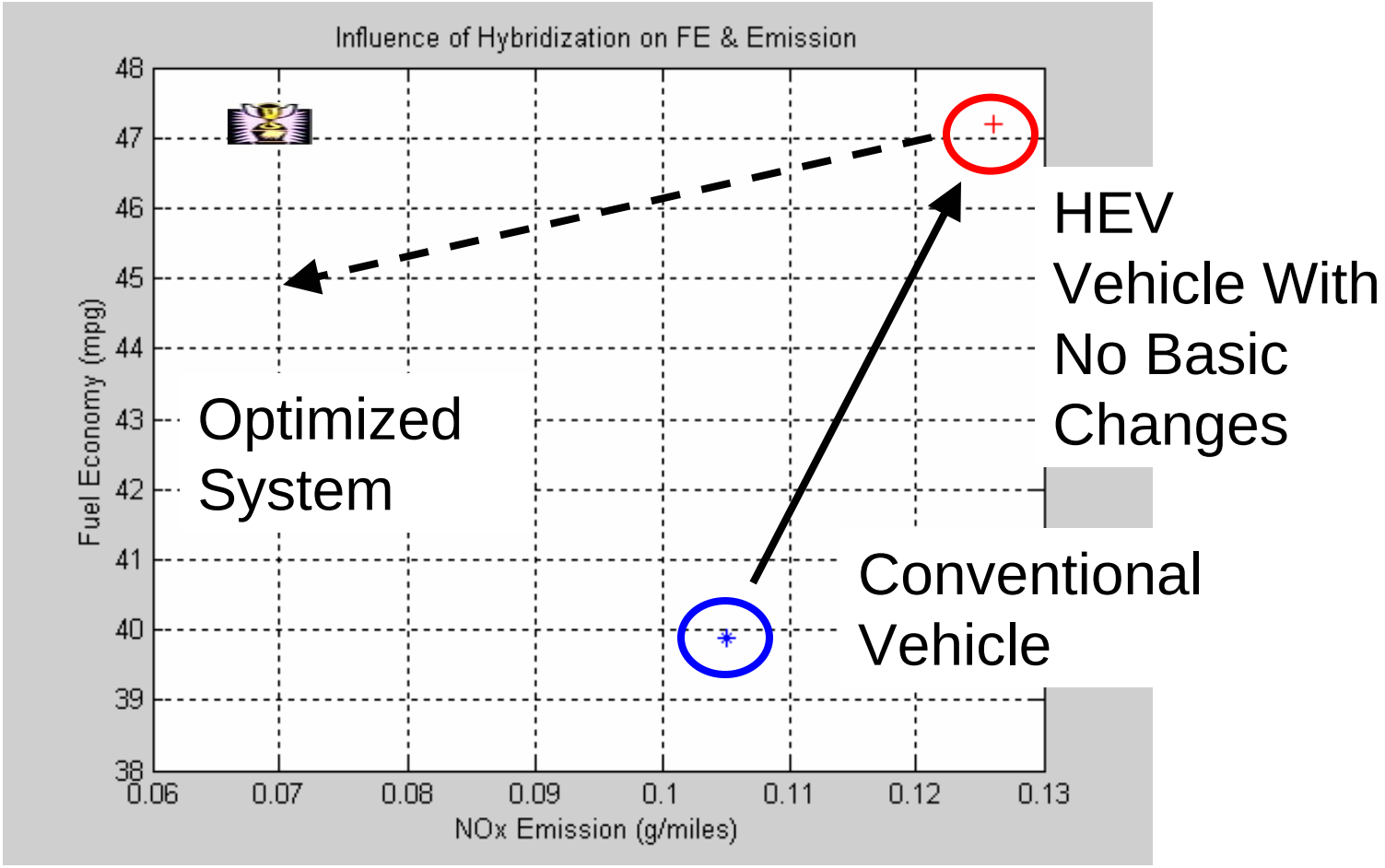
# *Hybridization Increases FE By Using The Best Engine Efficiency Curve*




Conventional Vehicle Operating Points

Hybrid Electric Vehicle Operating Points

# *Without Basic Changes In The Powertrain, Hybridization Improves FE, but May Increase NOx Emissions !*



# *Perspectives*

- Fuel economy and emission trade-off methodology has been demonstrated
- System optimization is needed to resolve the diesel emission issues (because engine control might not be sufficient).
- Preliminary simulation results are dependent on components and driving cycle and need to be validated using HIL