Simulation of Fuel Economy of Ammonia-Gasoline-Ethanol Tertiary Fuel for a Hybrid Electric Vehicle

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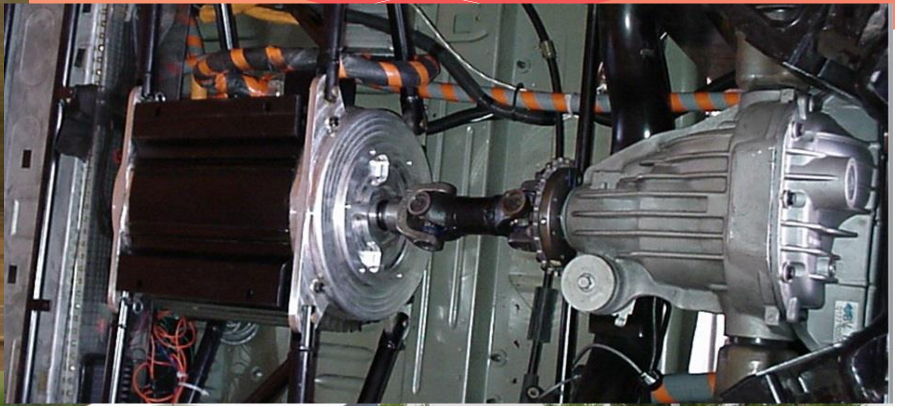
Motivation

* Ammonia – future transport fuel
* Ammonia-gasoline blends to commercialize ammonia
* Basis to compare fuel efficiency
  * Electricity v. gasoline
  * Renewable fuels v. gasoline
  * Electric/hybrid v. ordinary vehicle
* Texas Tech University in automotive competitions
  * Since 1980
  * DOE and/or industry sponsored
  * Modeling and simulation techniques

Motivation (Contd.)



Methodology

* Experiment based fuel performance
  * Dynamometer test results
* Model Based System Development
  * De facto Industry process
  * GM powertrain development with 1 million parts
  * Used to model complex electro-mechanical systems
  * Control, signal processing and communication

Methodology

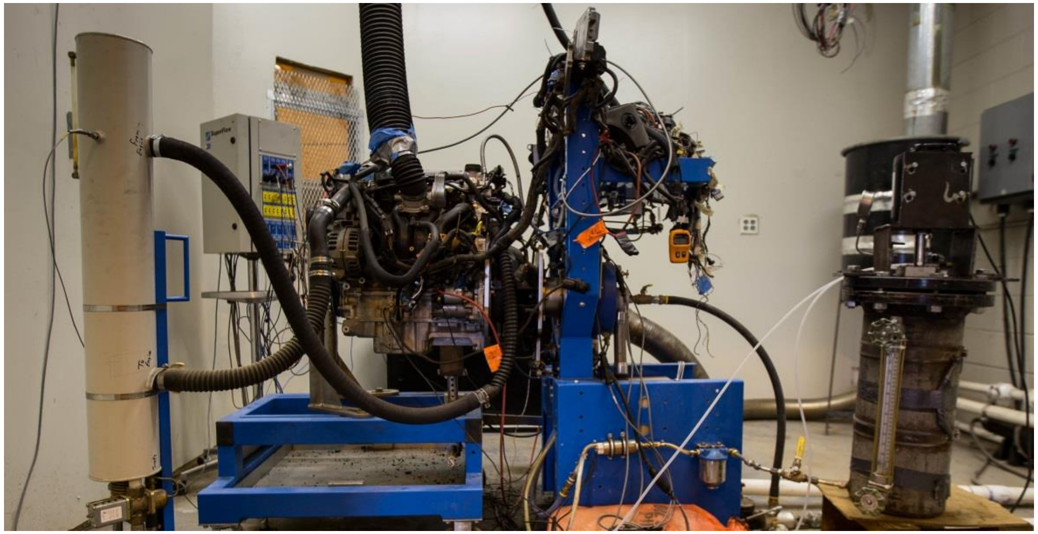
* Series hybrid electric vehicle (HEV) used for simulation
* First order battery model and experiment based engine model
* Engine dynamometer test carried out to model the engine
* Matlab-Simulink used for modeling [4-9]
  * System and component level architecture
  * Control and communication

Methodology (Contd.)

* Argonne National Lab (ANL) MPGge method [3]
  * Developed to calculate energy efficiency of renewable fuels
  * Single standard to calculate and compare MPG
  * Based on Energy content of Reformulated Gasoline (RFG)
  * 114871 BTU/gal
  * MPG of test fuel converted to RFG equivalent

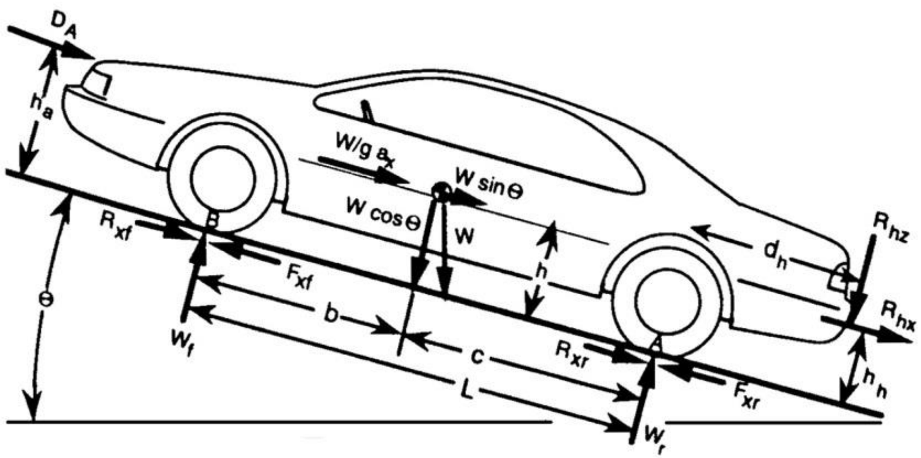
Experimental Setup

* Dynamometer testing of developed fuel blends
  * Superflow 902 engine dynamometer
  * GM Ecotec 2.4L gasoline engine
* Housed in Advanced Vehicle Engineering Building at Reese
* Benchmark the performance of baseline and ammonia rich fuels



* Three fuels were tested for simulation [10]
  * Ethanol free regular gasoline (E0)
  * Gasoline with 20% ethanol (E20)
  * Gasoline with 20% ethanol and 12.9% ammonia (E20A12.9)

Vehicle modeling and simulation setup



- **NSL provides the following relationship**

$$Ma_x = F_x - F_{roll_x} - F_{drag} - F_{hitch_x} - W\sin\theta$$

- **Define an equivalent mass of the rotating parts as**

$$M_r = \frac{(I_e + I_t)N_{tf}^2 + I_d N_f^2 + I_w}{r^2} \qquad F_x = \frac{T_e N_{tf}\eta_{tf}}{r} - \left\{(I_e + I_t)N_{tf}^2 + I_d N_f^2 + I_w\right\}\frac{a_x}{r^2}$$

- **Define effective mass and mass factor as**

$$M + M_r \quad \text{and} \quad \frac{M + M_r}{M}$$

- **Then**

$$(M + M_r)a_x = \frac{T_e N_{tf}\eta_{tf}}{r} - F_{roll_x} - F_{drag} - F_{hitch_x} - W\sin\theta$$

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7. Vehicle modeling and simulation setup (Contd.)

- **Level ground, no hitch forces**

$$\left(1+m_r\right)m\frac{dV}{dt}=\frac{T_m G_r \eta_{dl}}{R_t}-mgf_r-\frac{1}{2}\rho V^2 C_D A_f$$

- **Nomenclature**

m mass of vehicle ~ 3000 lbm

m_r represents rotating inertia ~ 0.15

V vehicle velocity in [ft/sec]

t time in [sec]

T_m torque supplied by motor (a function of motor speed) [ft–lbf]

- **Pair of ordinary differential equations**

$$\frac{dV}{dt}=\frac{1}{\left(1+m_r\right)m}\left\{\frac{T_m G_r}{R_t}-mgf_r-\frac{1}{2}\rho V^2 C_D A_f\right\} \qquad V(0)=0$$

$$\frac{dx}{dt}=V \qquad x(0)=0$$

Vehicle modeling and simulation setup (Contd.)

* Simulated Vehicle Specs.
  * Passenger car
  * Mass – 1200 kg
  * Frontal area – 3 m^2
  * Drag coefficient – 0.4

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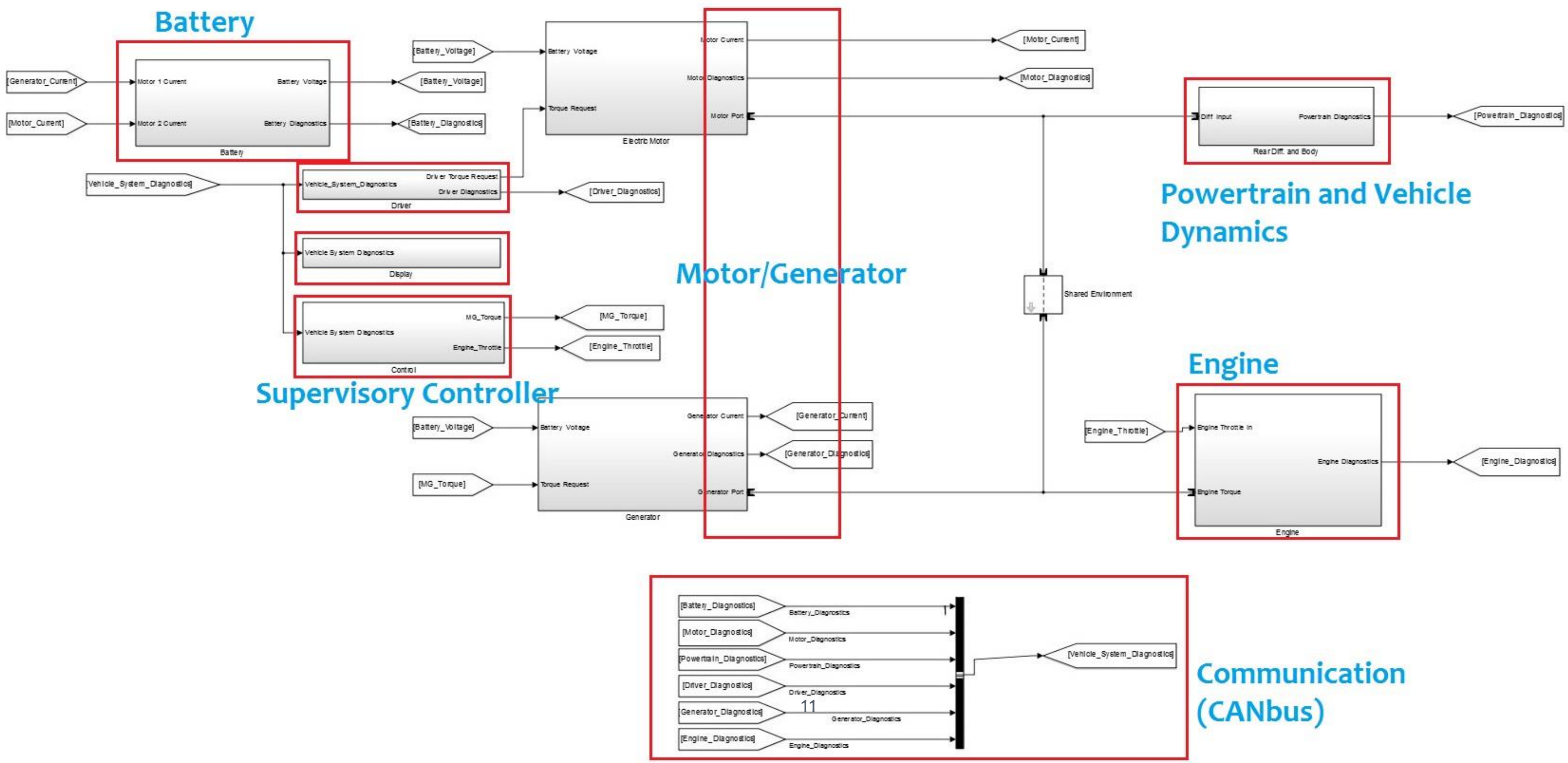
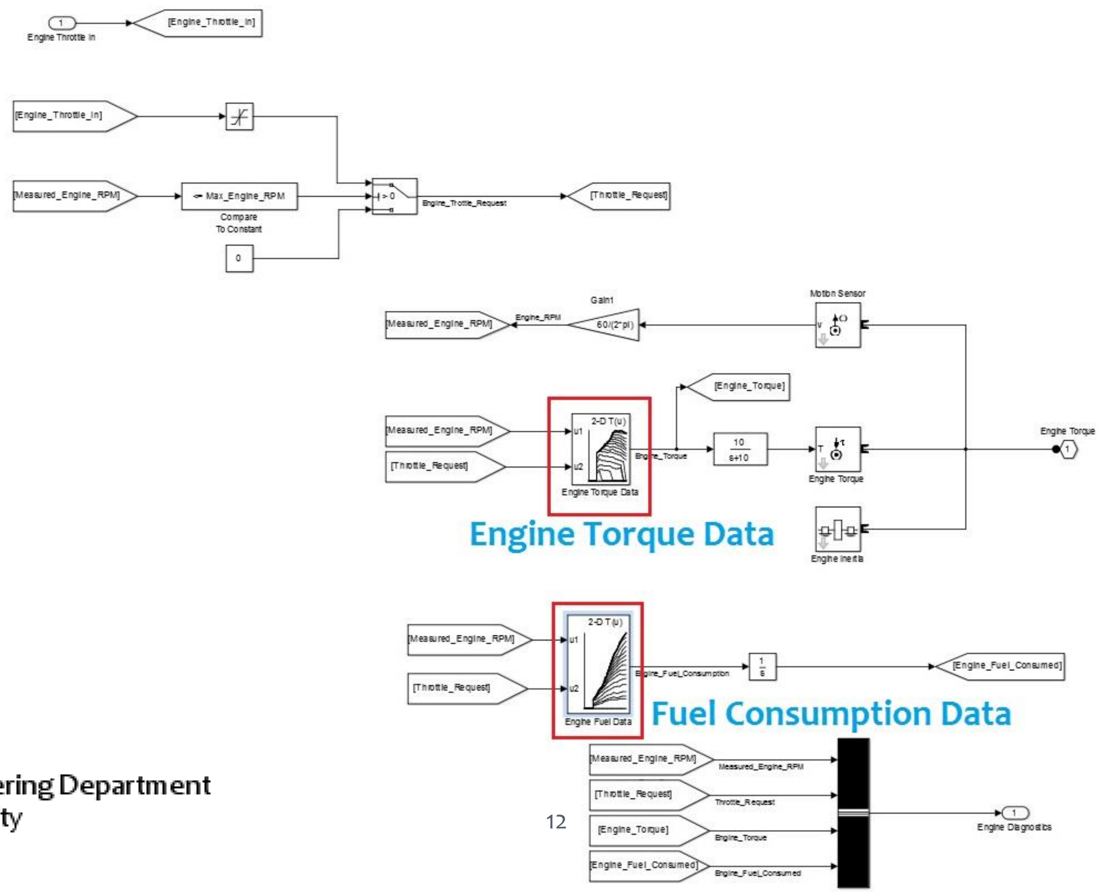
Vehicle modeling and simulation setup (Contd.)

* Simulink MBSD Model



Vehicle modeling and simulation setup (Contd.)

- Engine Modeling

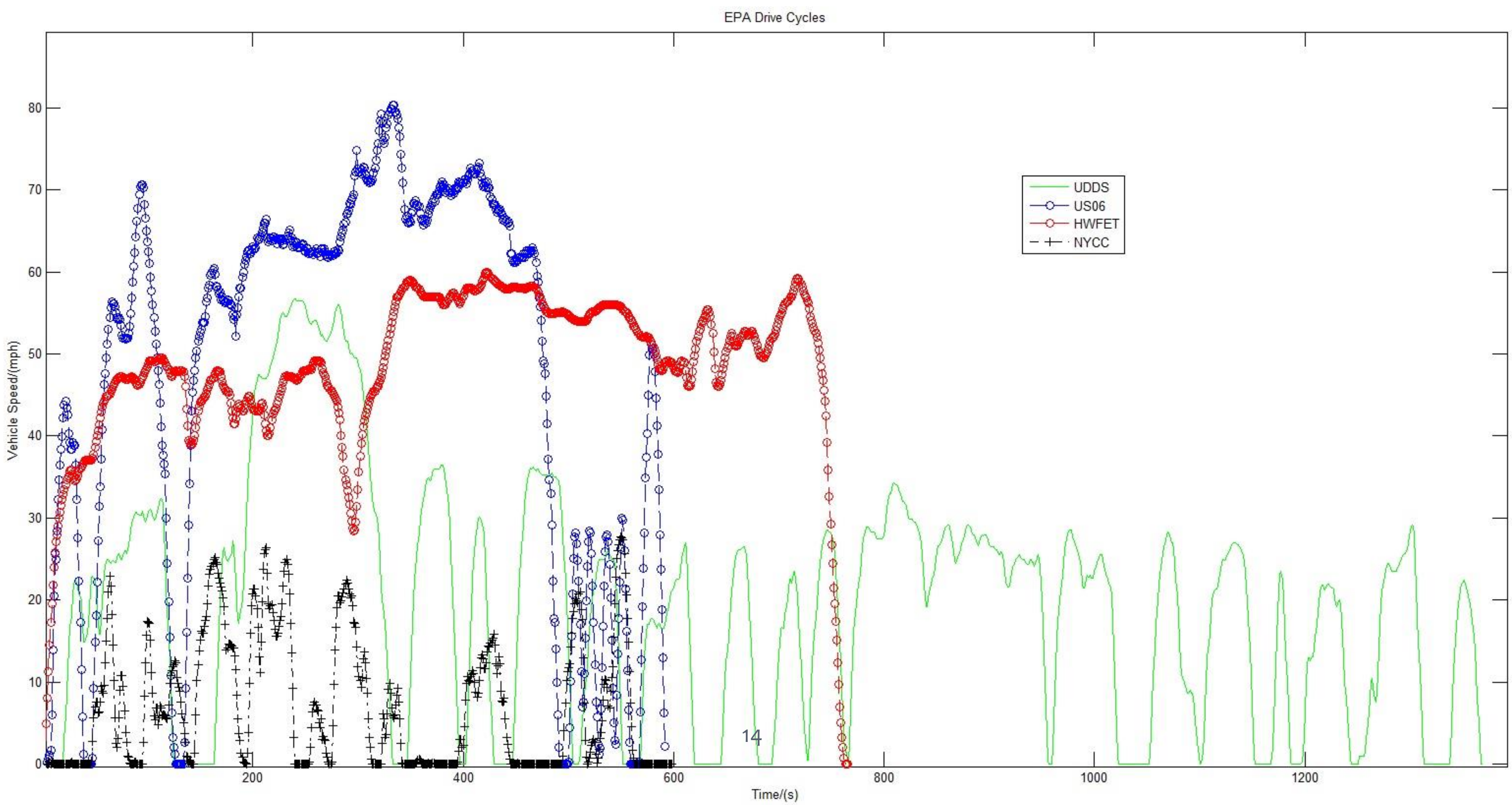


Vehicle modeling and simulation setup (Contd.)

* Four EPA drive cycles were used for simulations [11]
* Federally regulated standard cycles
  * Urban Dynamometer Driving Schedule (UDDS)
  * Aggressive Driving Schedule (US06)
  * Highway Fuel Economy Driving Schedule (HWFET)
  * New York City Cycle (NYCC)

Vehicle modeling and simulation setup (Contd.)

* EPA drive cycles



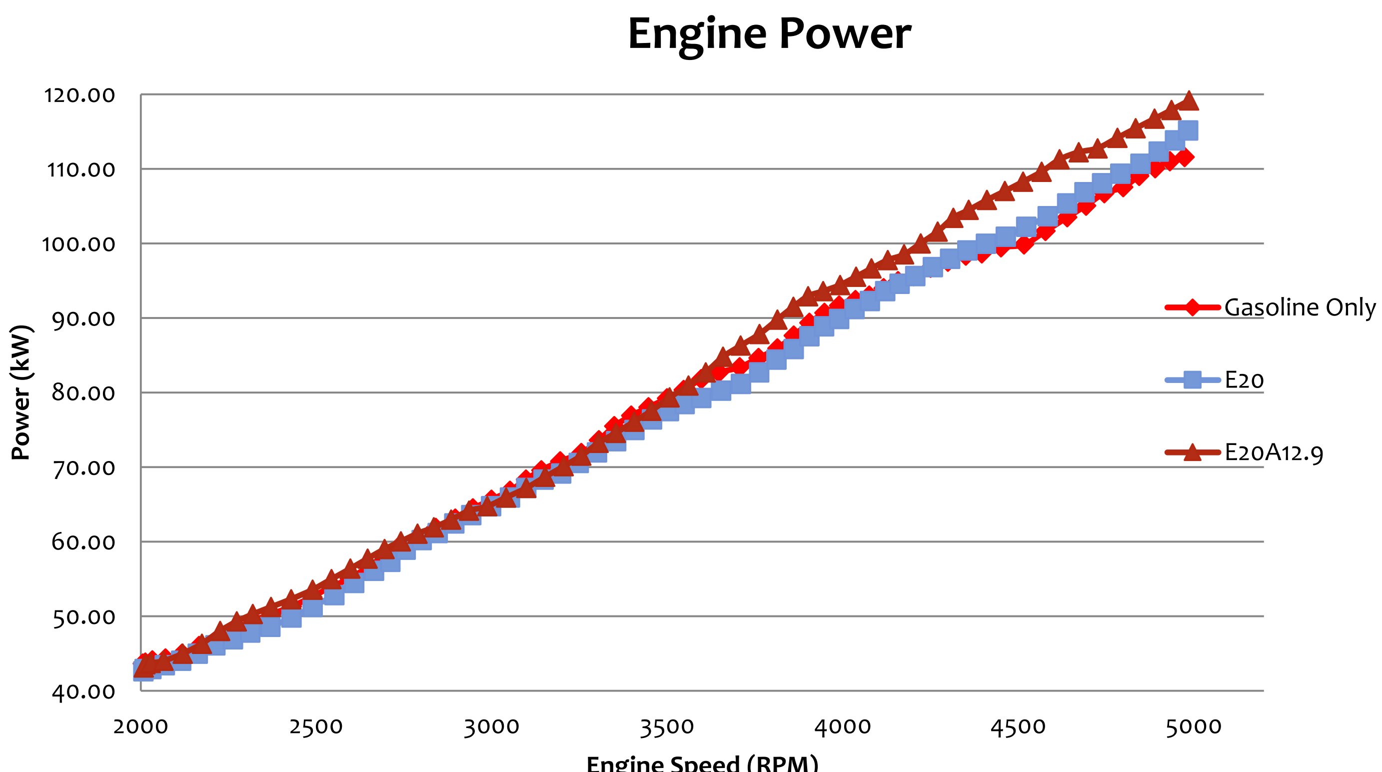
Results

* Energy content based on enthalpy of formation
* Used for MPGge conversions

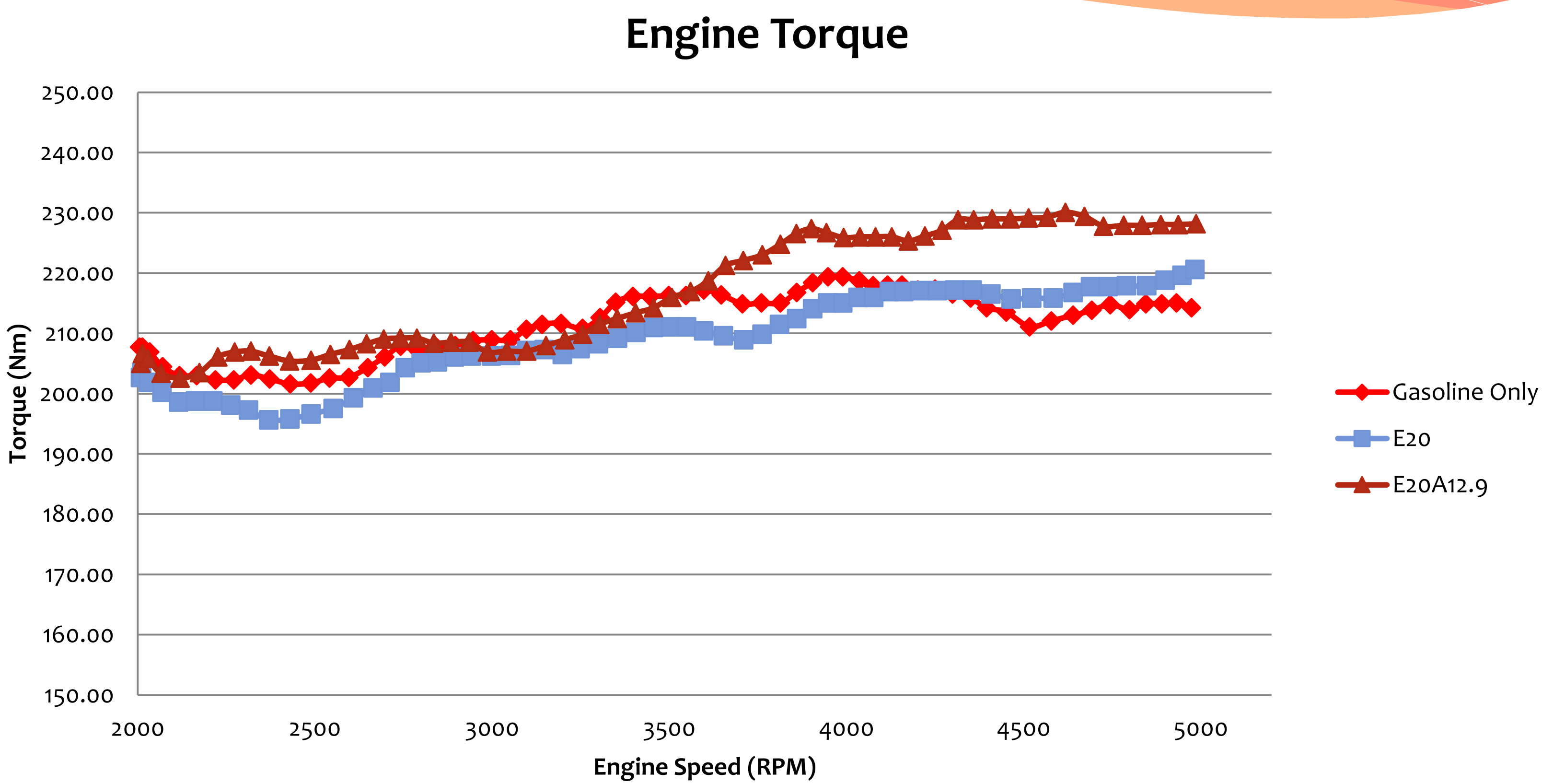
Fuel	Weight (g/gal)	Energy Content (BTU/gal)
RFG	2845	114872
E0	2839	126472
E20	2864	119369
E20A12.9	2804	111180

Results (Contd.)

* Dynamometer results



Results (Contd.)



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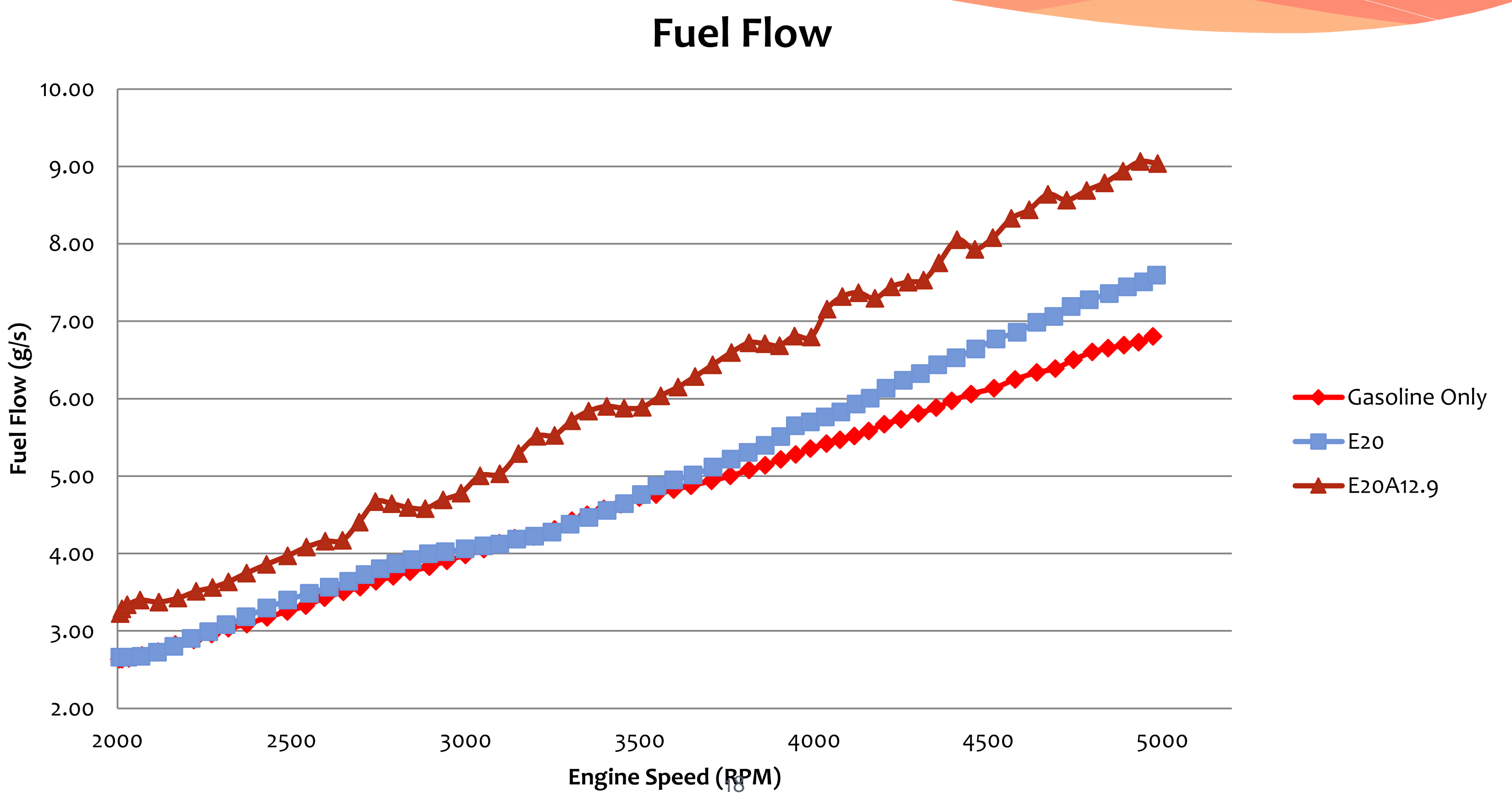
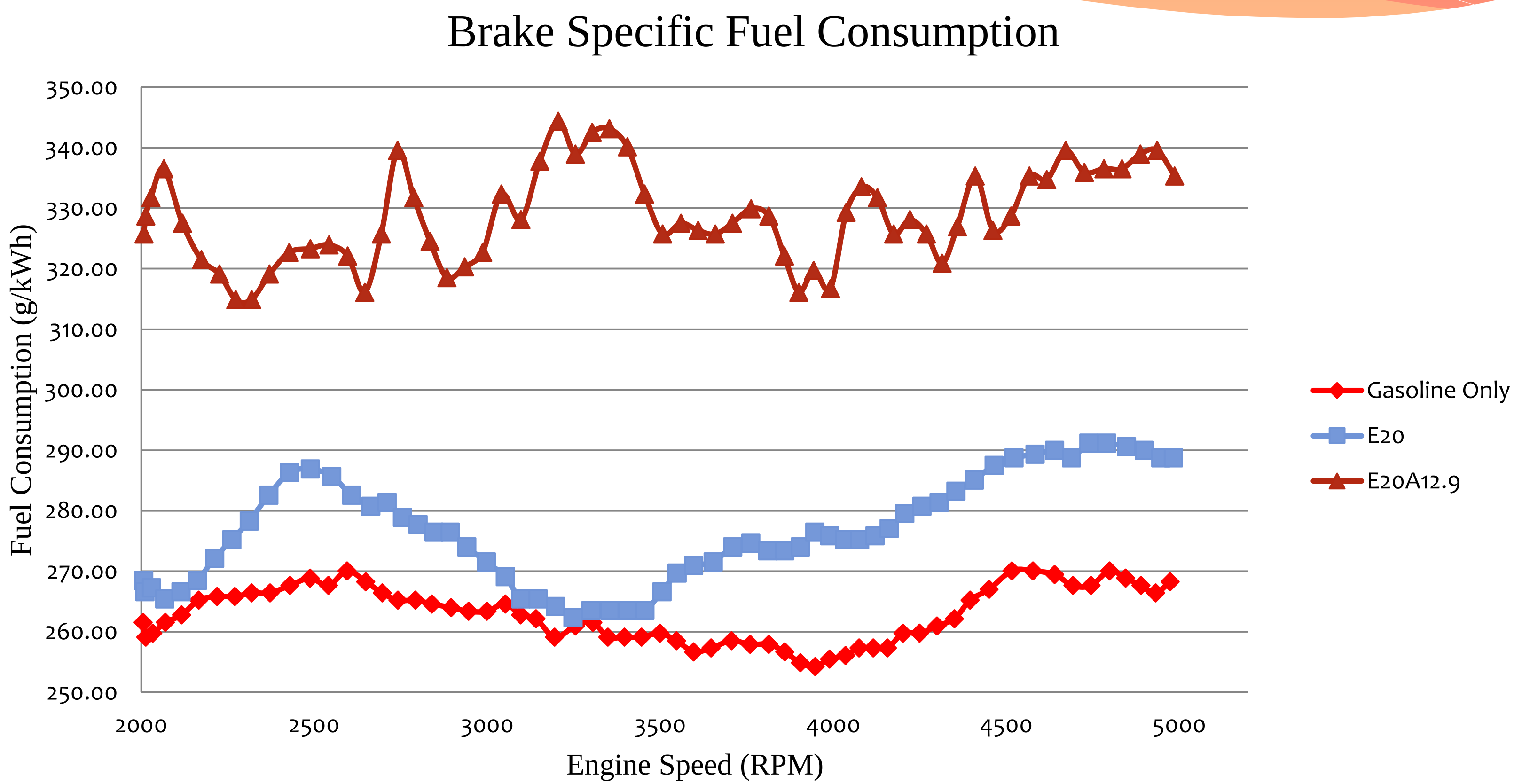
Results (Contd.)

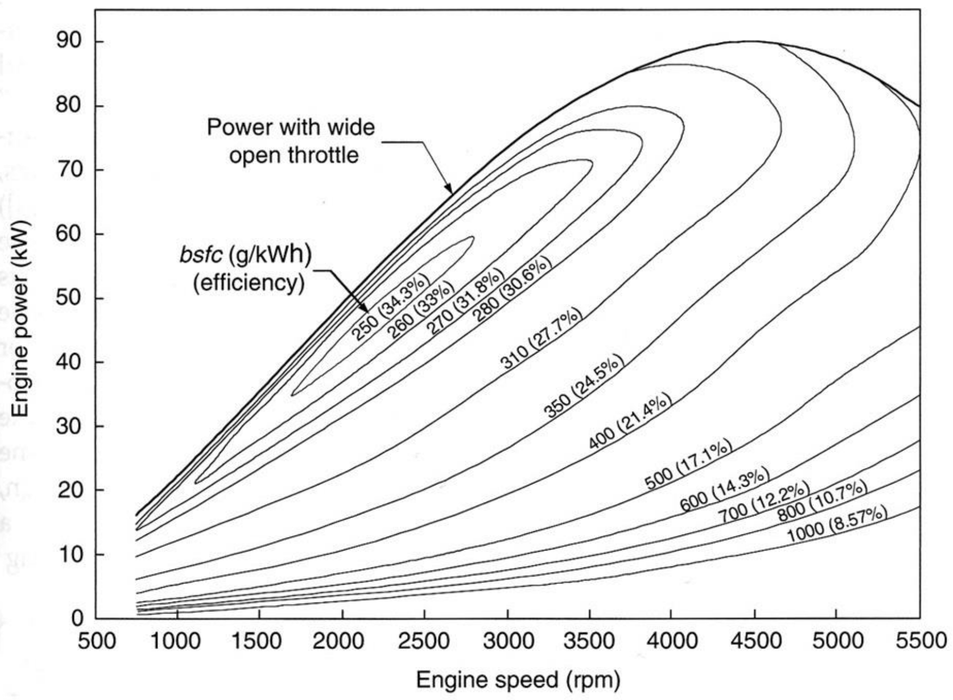


Results (Contd.)



Results (Contd.)

* Fuel consumption characteristics of a typical gasoline engine [7]
* Best - 250 g/kWh
* 34.3% efficiency
* Engine dynamometer tests
  * 255 g/kWh to 345 g/kWh



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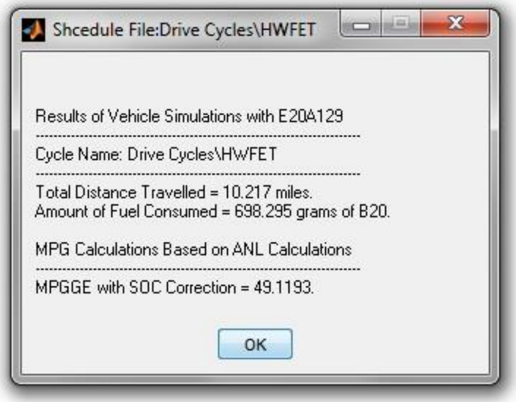
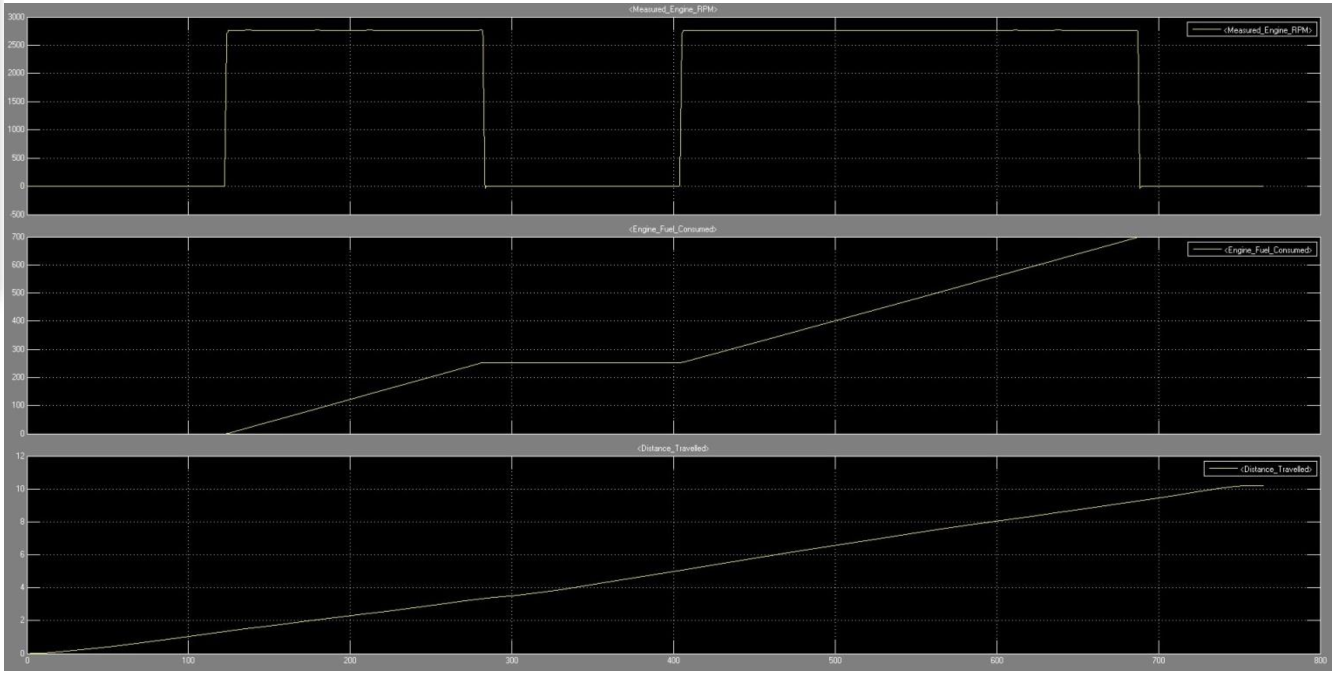
Results (Contd.)

* Simulation Results





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Results (Contd.)

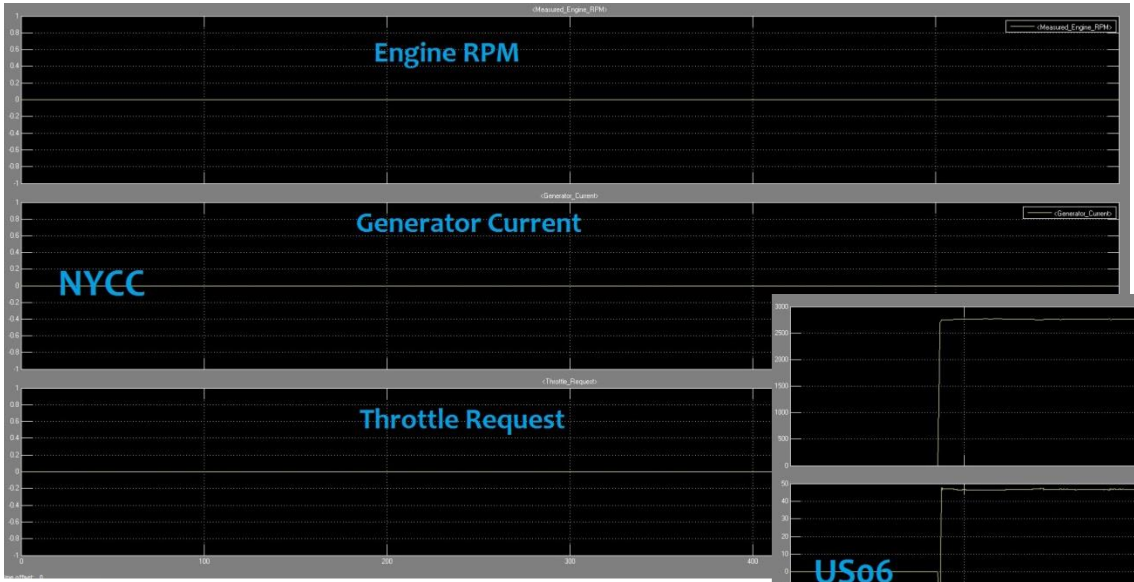
* Final simulation results (MPGge)

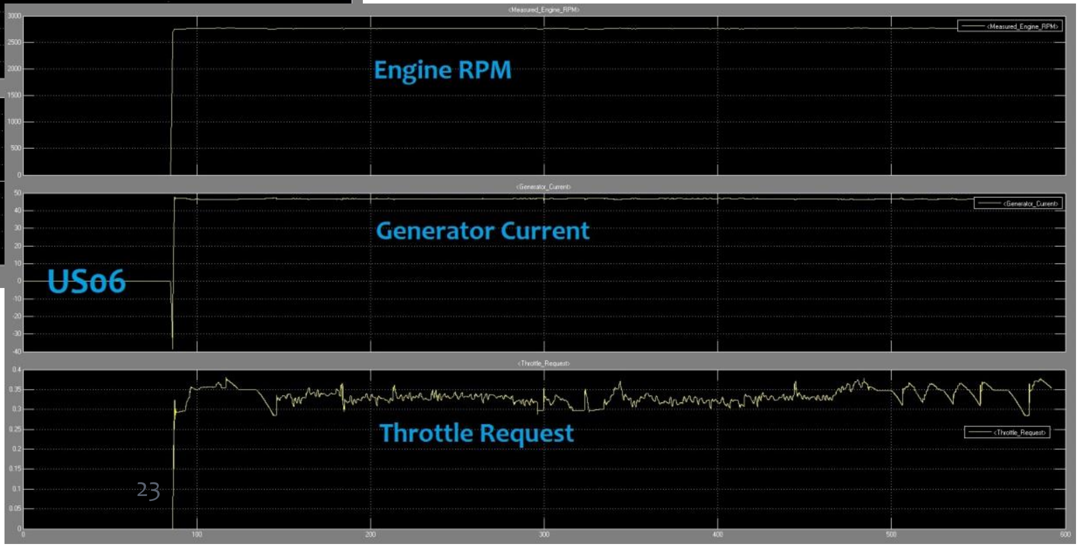
Drive Cycle	E0	E20	E20A12.9
UDDS	83.7	84.5	85.1
US06	30.6	30.93	31.2
NYCC	108.3	108.3	108.3
HWFET	40.04	48.7	49.1

* Chevrolet Volt [12]
  * 98 MPGge (Electric only)
  * 37 MPG (Combined city and highway)
* Comparable results

Conclusions

* MPGge - 108.3 (NYCC) v. 31.02 (US06) ?





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Conclusions

* BSFC/Fuel flow is higher for E20A12.9
* Higher MPGge for E20A12.9
* Based on ANL - RFG standard, ammonia rich fuel has capability to produce better MPGge
* Capability to simulate fuel economy for
  * Engines in development phase
  * Different vehicle types

Potential improvements

* Control strategy
  * All dynamometer tests were carried out at full throttle
  * Linear relationship was assumed between "No throttle" and "Full throttle"
* Only regenerative braking was modeled
* Cane be improved to real operating conditions

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Thank you …

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