ILLINOIS INSTITUTE OF TECHNOLOGY

IPRO 342: Hybrid Electric Vehicles Simulation, Design, and Implementation

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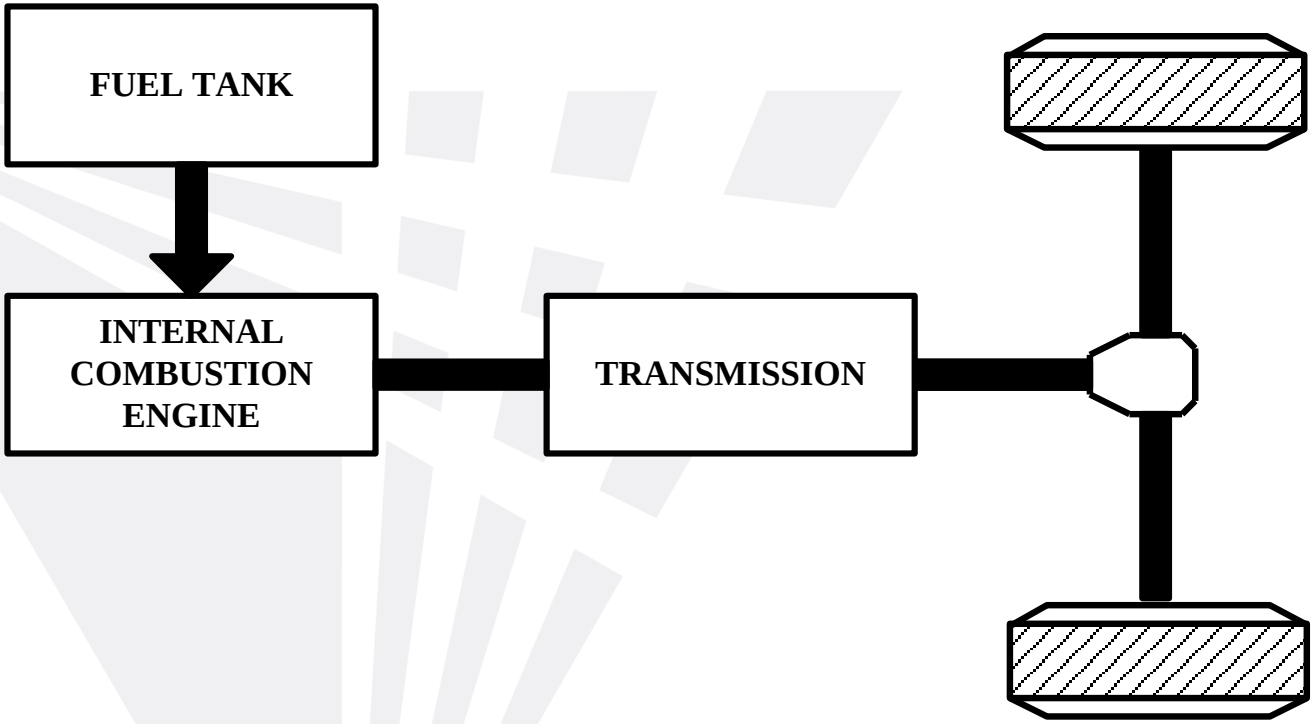
Presentation Outline

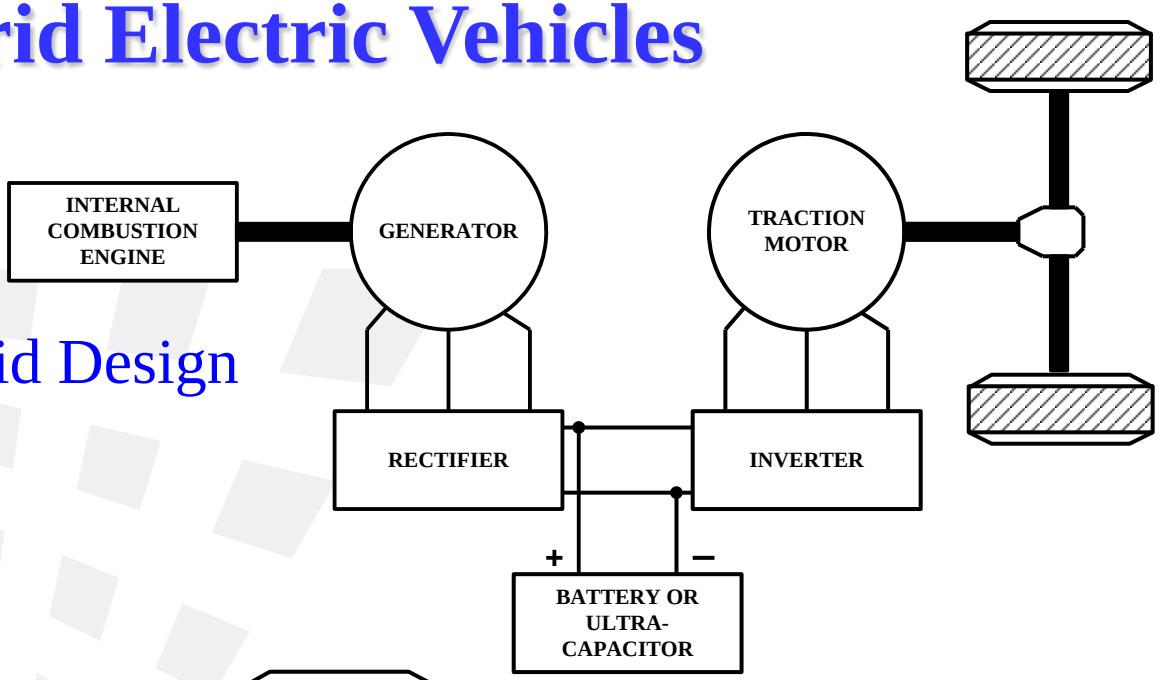
- Introduction to Hybrid Electric Vehicles (HEVs)
- Hybrid Buses
- Project Objectives
- ADVISOR Simulations
- Component Selection
- Mechanical Configuration
- Cost Analysis
- Conclusion and Future Work

Conventional Vehicles

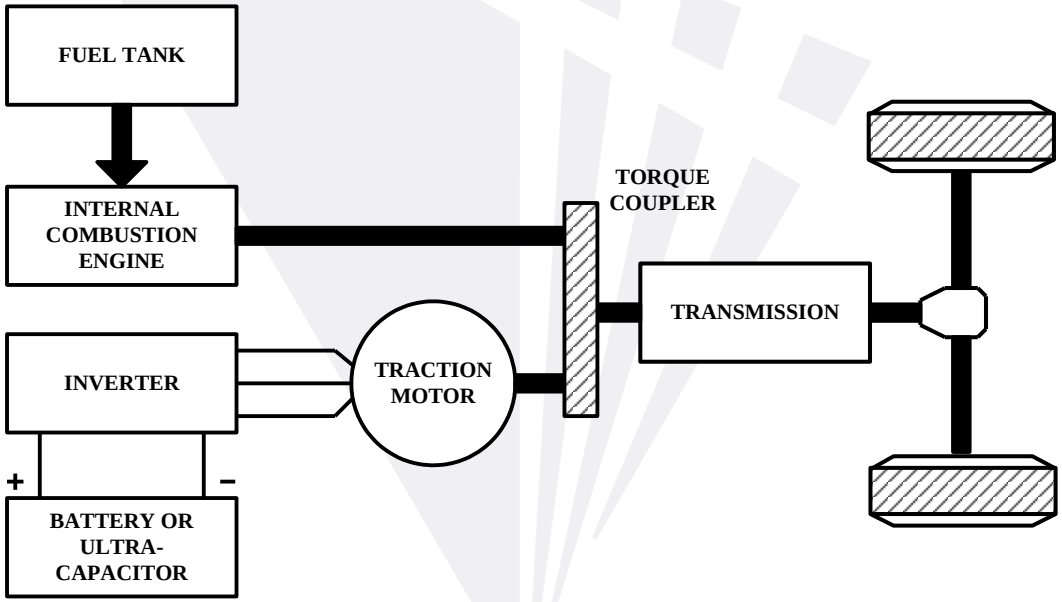


Maximum efficiency of 30 – 35 %

Hybrid Electric Vehicles



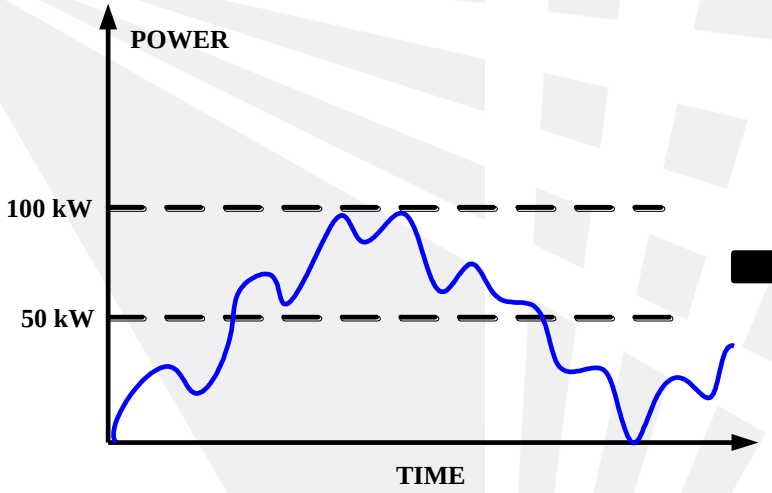
Series Hybrid Design



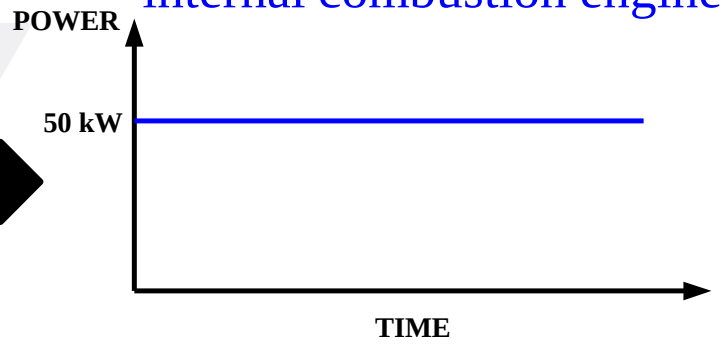
Parallel Hybrid Design

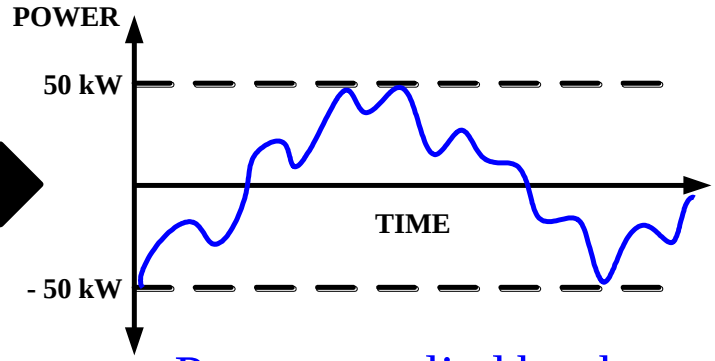
Goal of Hybrid Electric Vehicles

Power requirements over a drive cycle



Power supplied by the internal combustion engine





Power supplied by the electric motor

Reasons for Hybrid Buses

- High annual mileage
- High number of stops (regenerative braking)
- Predictable driving route
- Low fuel efficiency
- High emissions
- Budget shortfalls

Project Objectives

- Determine designs for CTA and Blue Bird Vision bus
- Simulate designs using ADVISOR software
- Select components based on simulation results
- 3D modelling of mechanical configuration
- Perform initial cost analysis

Design Selections

Blue Bird Vision bus

- Parallel Retrofit
- Parallel New Design
  - Downsized engine
  - More flexibility
- Parallel Integrated Starter Alternator (ISA) Design

CTA bus

- Parallel Retrofit

Why Retrofit?

New Conventional Bus Price:
$300,000

New Hybrid Bus Price:
$500,000

Estimated Retrofit Price:
$10,000 per bus

ADVISOR 2002

Advanced Vehicle Simulator

Units:

- Metric
- US

all_menus

Start

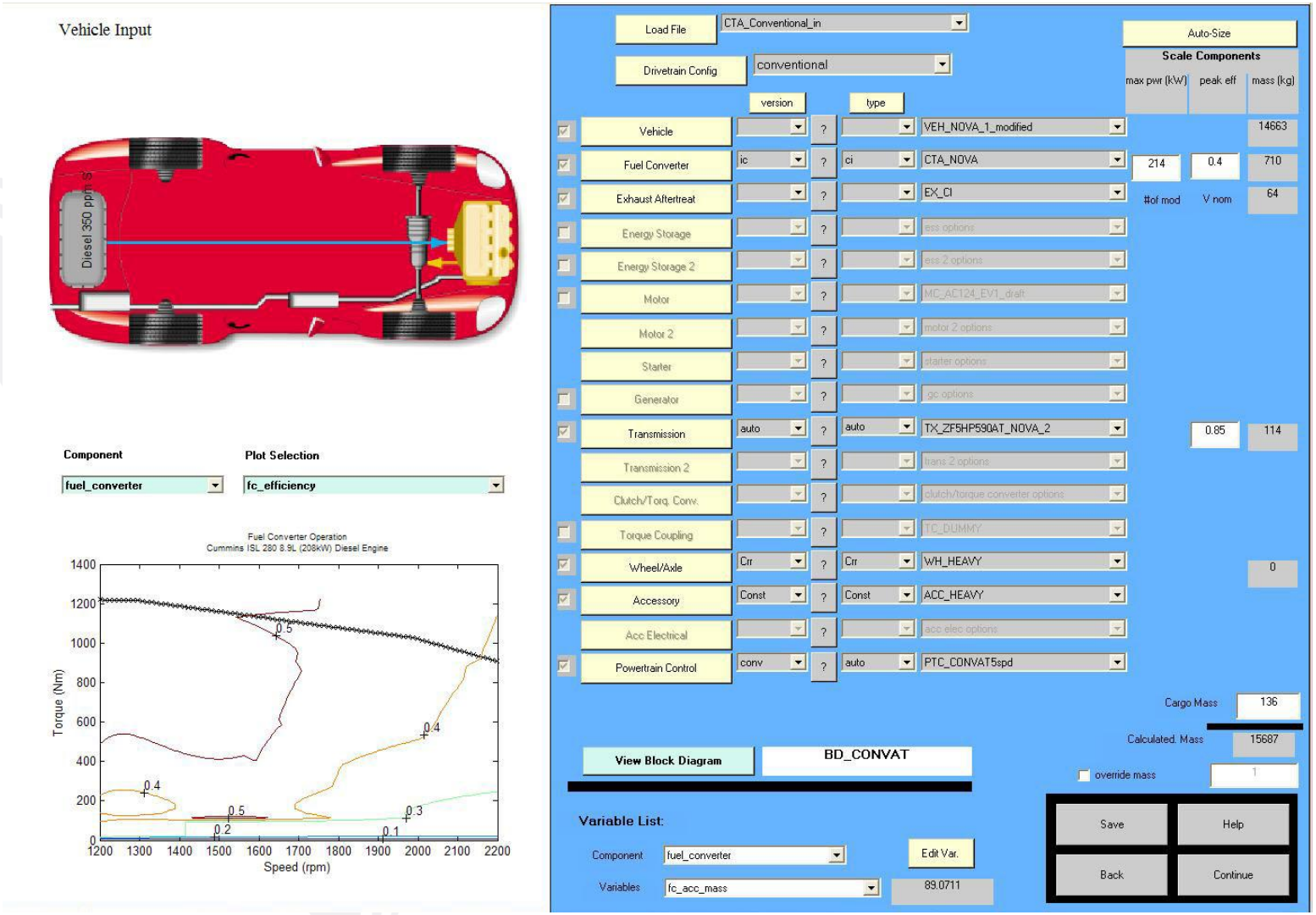
Help

© and Disclaimer

Exit

Load Results

Simulating ADVISOR



Result Screens: How to Judge Success

Fuel Economy

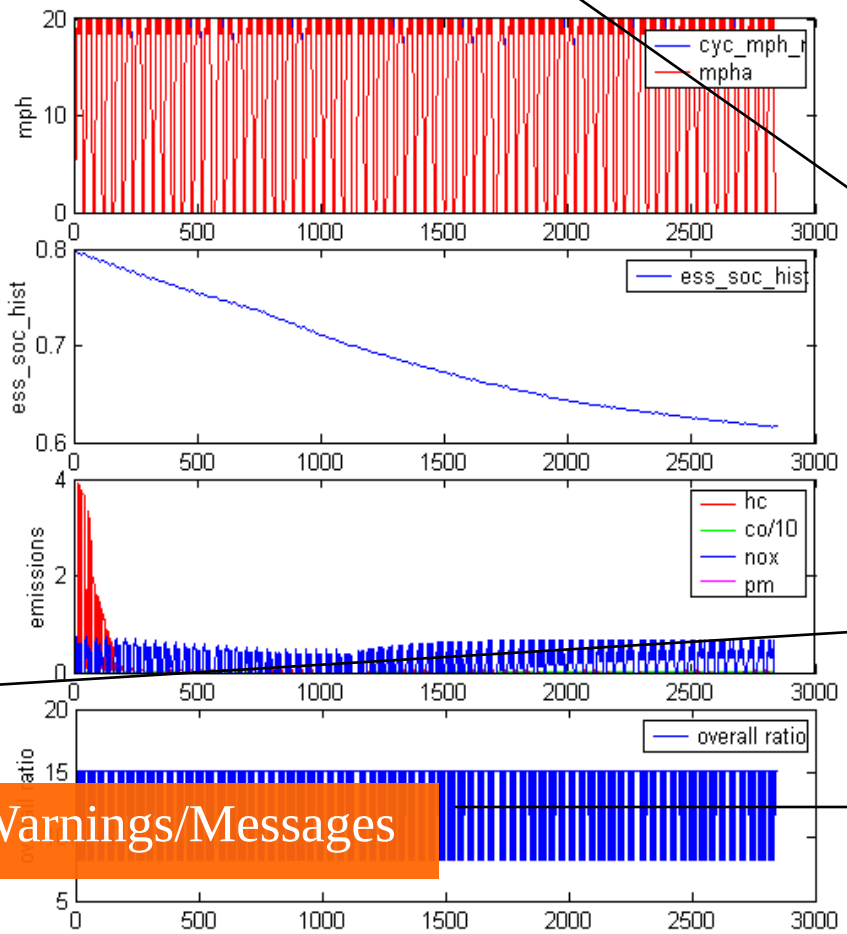
Drive Cycle

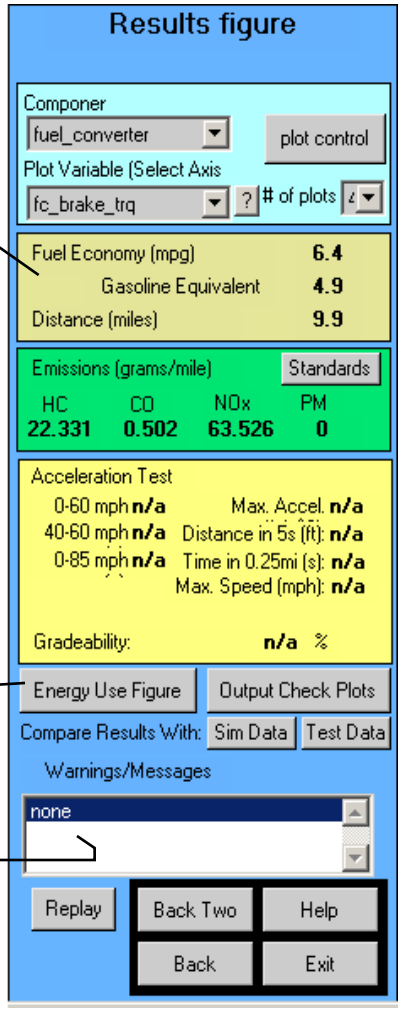
Battery SOC

Emissions

Energy Use and Output Plots

Warnings/Messages





CTA: NOVA BUS LFS

- In 2001, 483 NOVA LFS-model Buses were purchased by CTA.
- Pending available funding, the 6400 Series will likely go through a mild-life rehab later in the decade.

- Engine: Cummins ISL 8.3L 280 HP (208kW)
- Transmission: ZF Ecomat Automatic Transmission Series: HP 592C

ADVISOR Customization

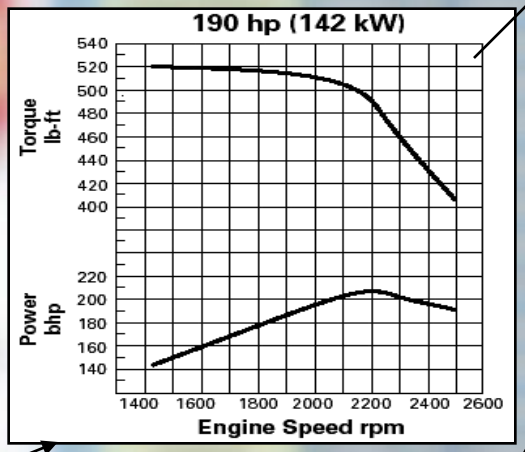
Conventional Vehicle Specifications

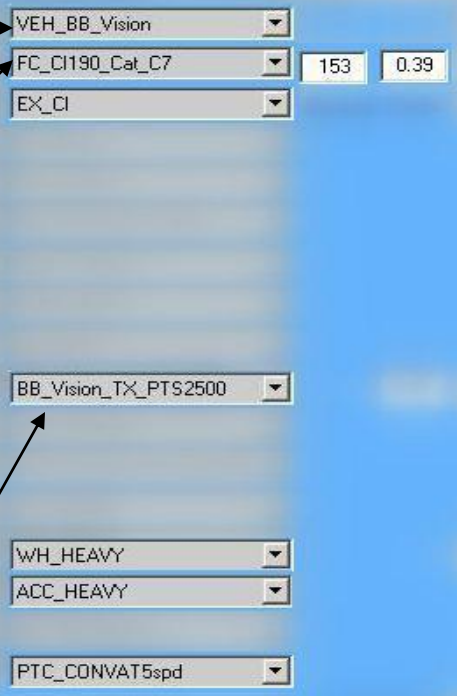
< Table 1. Vehicle Component >

Length:	488 in.
Width:	102 in.
Height::	123 in.
Wheel Base:	244 in.
Gross Vehicle Mass:	17690.3 kg

< Table 2. Engine Performance Data >

Operating Range (rpm)	1200 – 2200
Max (kW)	215
Peak Torque — (N•m)	1220
Peak Torque Occurrence (rpm)	1200





< Table 3. Transmission Gear Ratio >

GEAR RATIOS - Torque Converter Multiplication Not Included					
MODEL	FIRST	SECOND	THIRD	FOURTH	FIFTH
ZF Auto	3.41	2.01	1.42	1.00	0.83

Drive Cycle

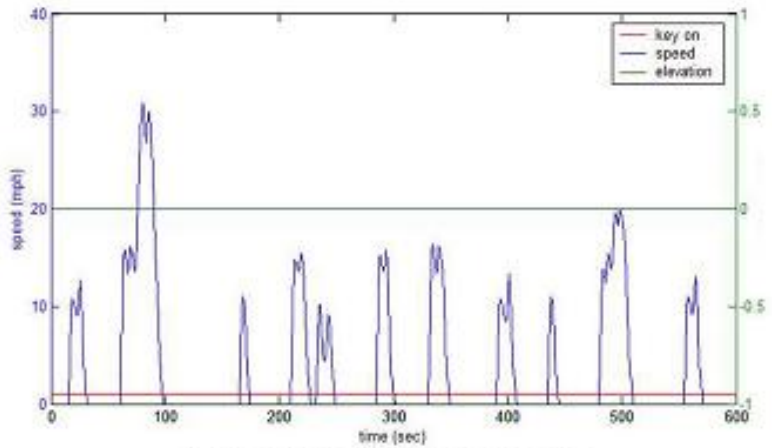


Fig.3 New York Bus Drive Cycle

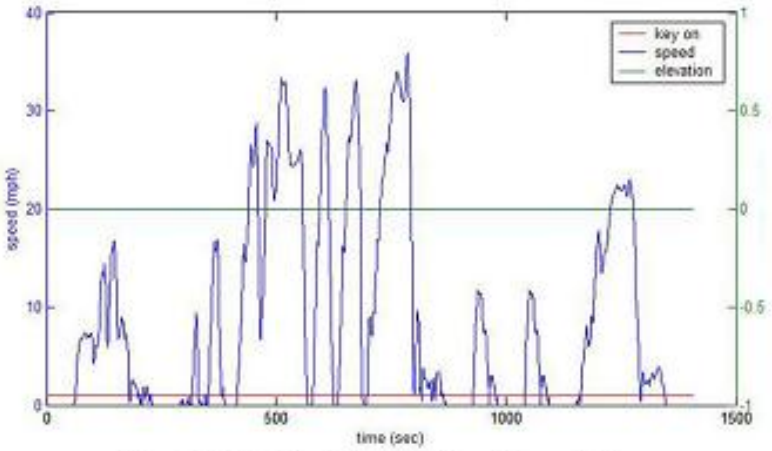


Fig. 4 West Virginia City Bus Drive Cycle

CTA NOVA BUS Simulation Results

- **Battery size: 46 Modules of 12V/85Ah Lead-Acid batteries**
- **Electric Motor size: 83kW AC Induction Motor**

	Drive Cycle	Fuel Efficiency	Improvement
Conventional	New York Bus	2.2 mpg	
Hybrid Bus	New York Bus	3.2 mpg	33%

	Drive Cycle	Fuel Efficiency	Improvement
Conventional	W. Virginia	3.6 mpg	
Hybrid Bus	W. Virginia	4.8 mpg	45%

Blue Bird Vision Simulations

Conventional Blue Bird Vision School Bus with Caterpillar C7 engine (153 kW)

Hybrid Models

1. **Parallel Retrofit:**
   Same engine + motor + batteries

2. **Parallel New Design:**
   Smaller engine + motor + batteries

3. **Parallel ISA New Design:**
   Smaller engine + motor + batteries

ADVISOR Customization

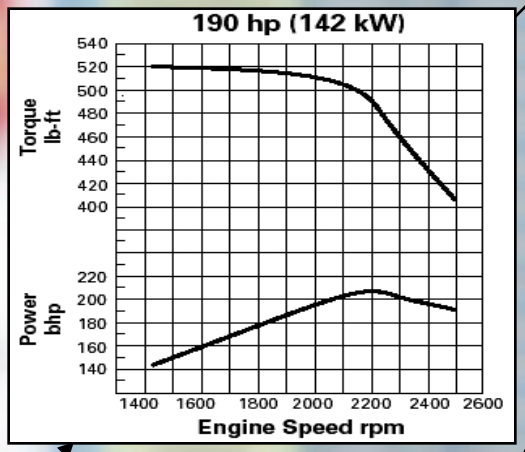
Conventional Vehicle Specifications

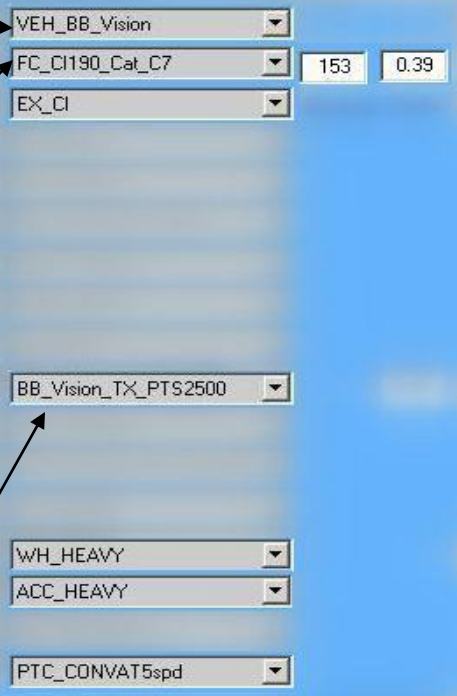
< Table 1. Vehicle Component >

Capacity	up to 54
Vehicle's Center of Gravity	0.774m
Front Axle Weight Fraction	0.3636
Wheel Base (54 pass.)	5.512 m
Vehicle Mass	8097 kg
Vehicle Cargo Mass (27 pass.)	1837 kg
Vehicle Front Area	6.859 m^2

< Table 2. Engine Performance Data >

Operating Range (rpm)	1440–2500
Governed Speed (rpm)	2500
Advertised hp (kW)	190 (142)
Max hp (kW)	207 (154)
Peak Torque — lb-ft (N•m)	520 (705)
Peak Torque — rpm	1440
Torque rise (%)	27
Altitude Capability — ft (m)	10,000 (3048)

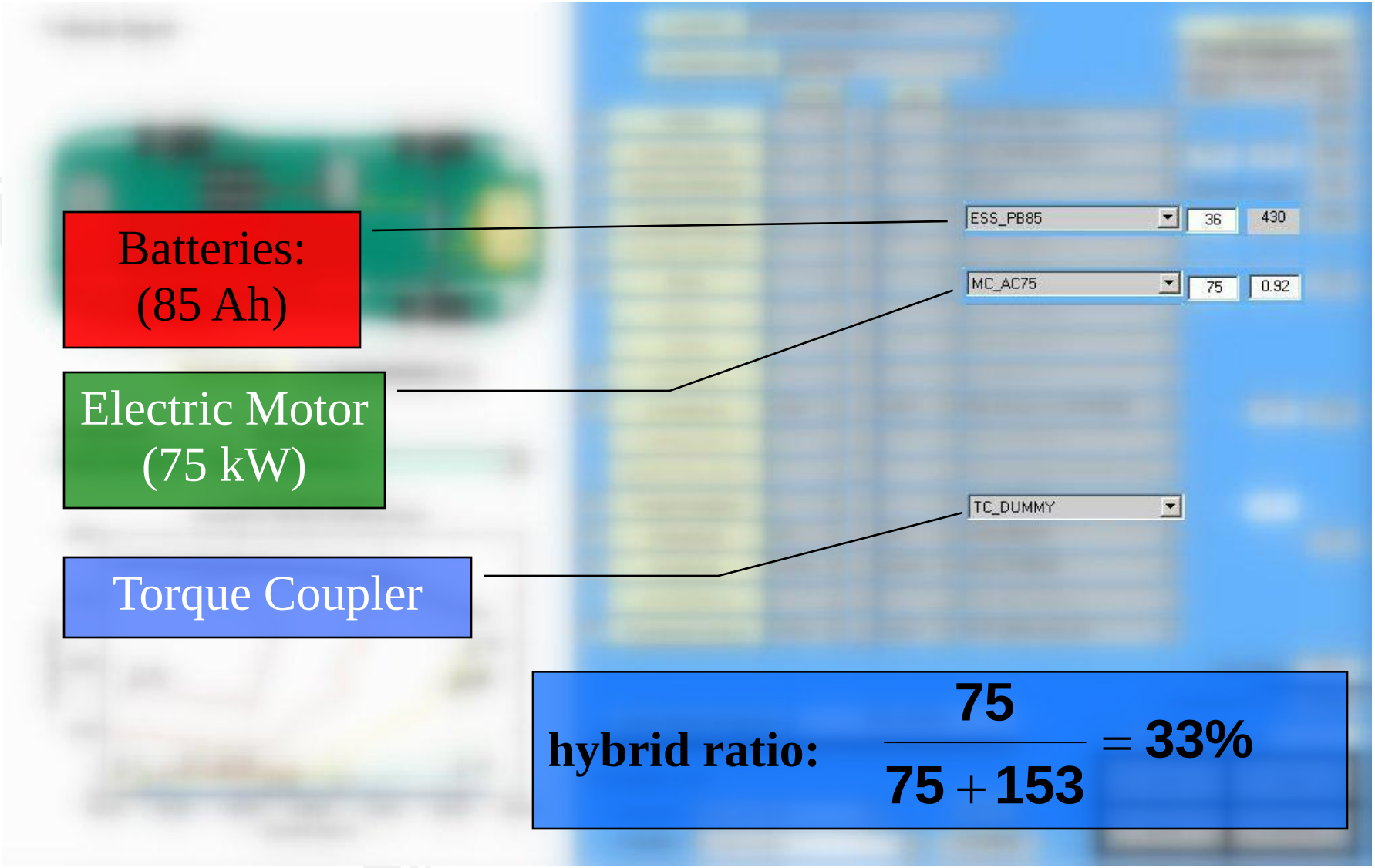




< Table 3. Transmission Gear Ratio >

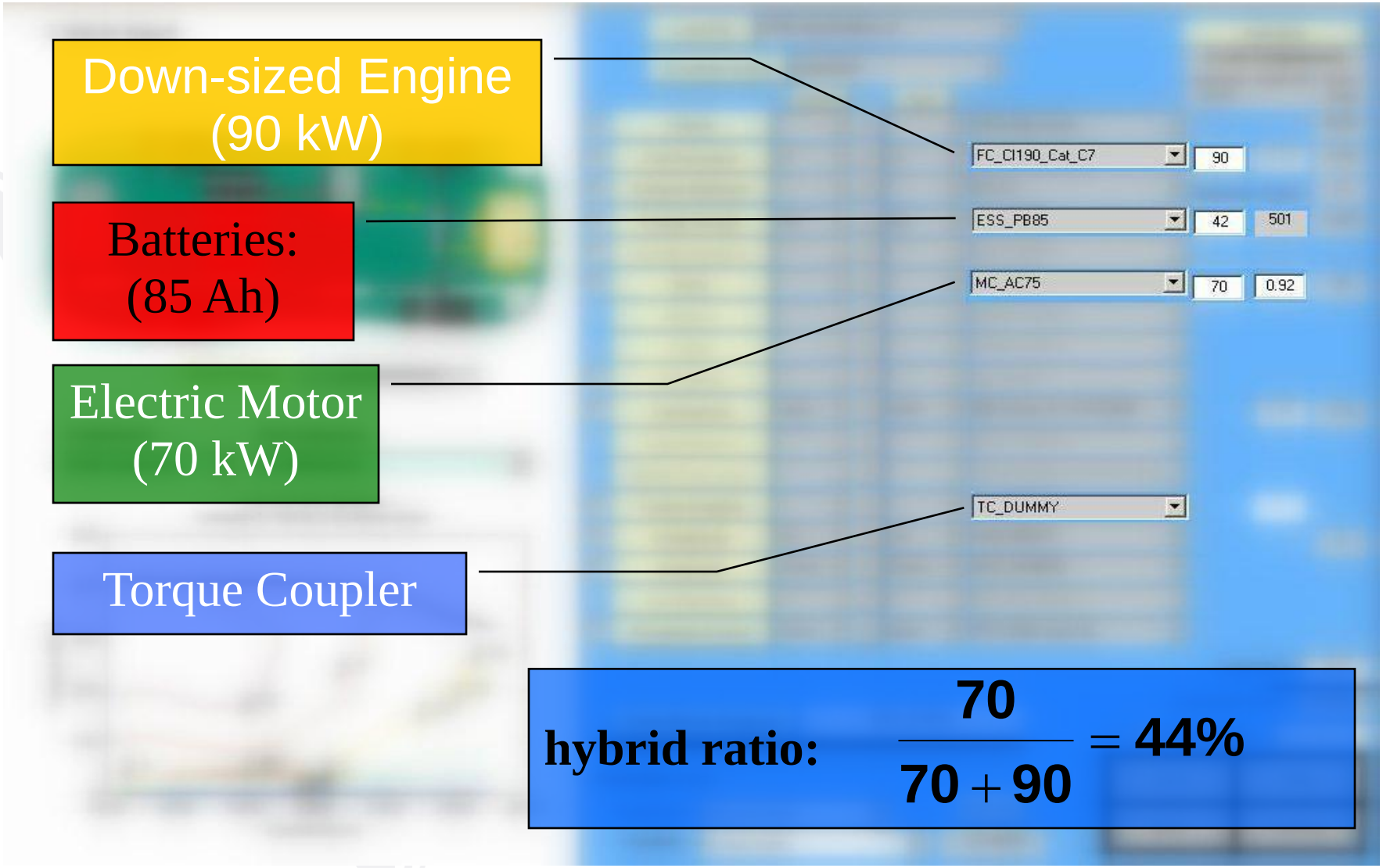
GEAR RATIOS - Torque Converter Multiplication Not Included						
MODEL	FIRST	SECOND	THIRD	FOURTH	FIFTH	REVERSE
2500 PTS	3.51:1	1.90:1	1.44:1	1.00:1	0.74.1	-5.09:1

Parallel Retrofit Specifications



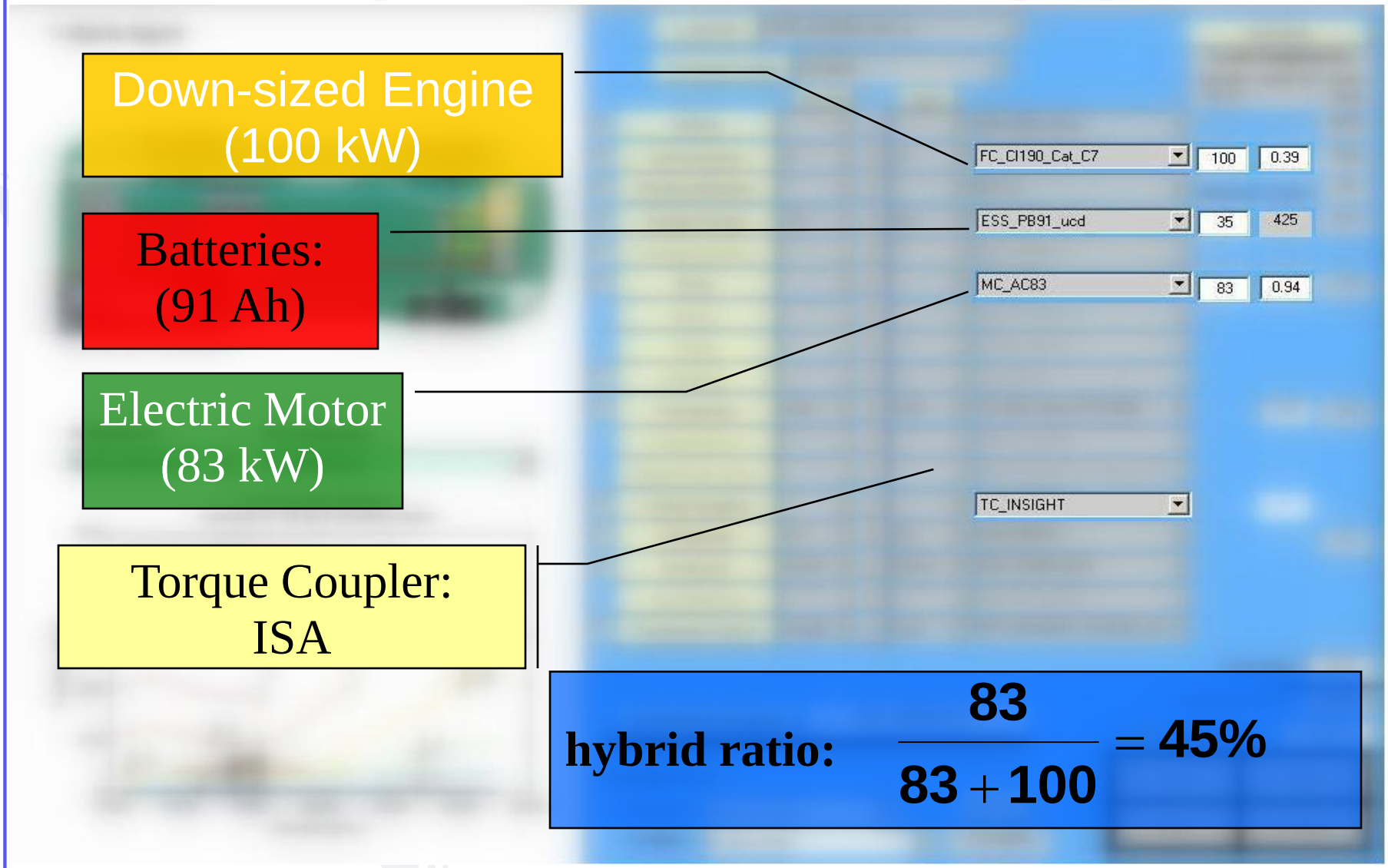
hybrid ratio: $\frac{75}{75+153} = 33\%$

Parallel New Design Specifications



hybrid ratio: $\frac{70}{70+90} = 44\%$

Parallel Integrated Starter-Alternator Design Specifications

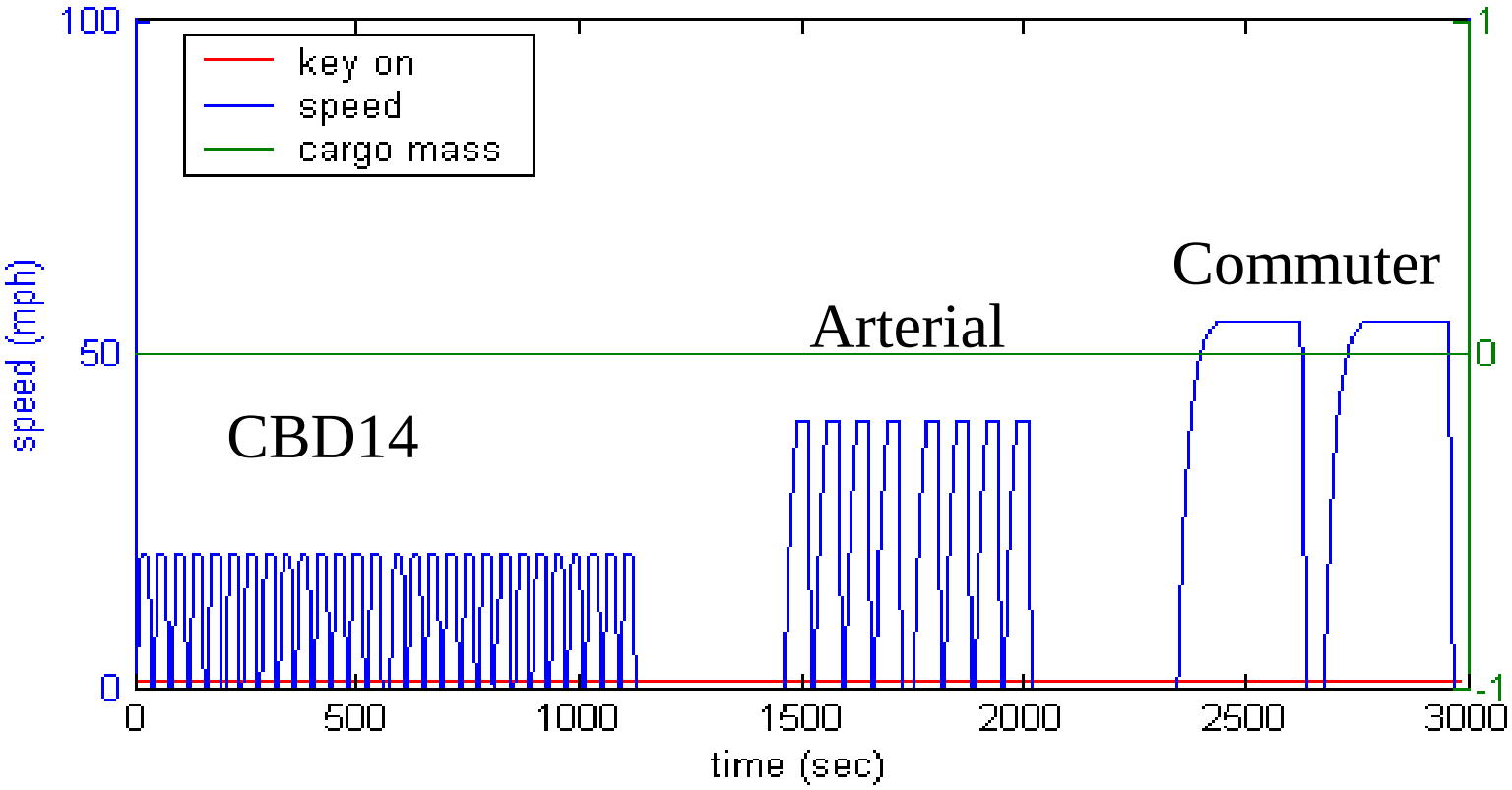


hybrid ratio: $\frac{83}{83+100} = 45\%$

Test Procedures: How to Measure Performance

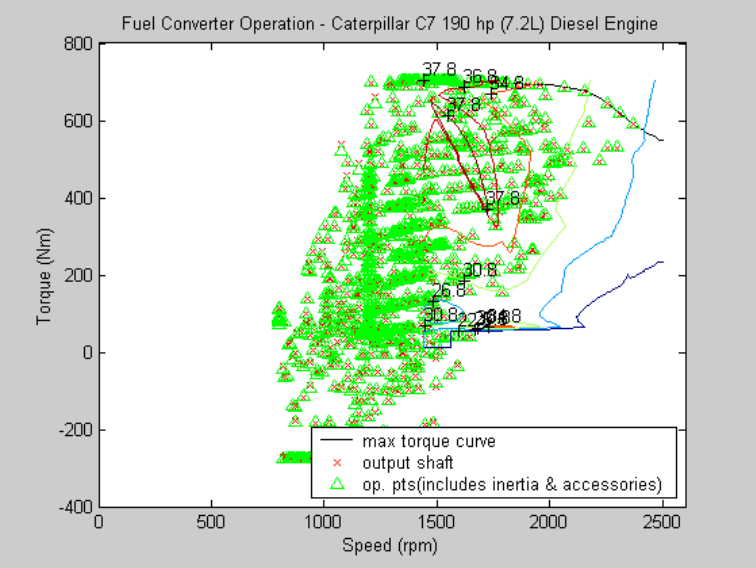
Drive Cycles

- **CBD14**
- **ARTERIAL**
- **COMMUTER**

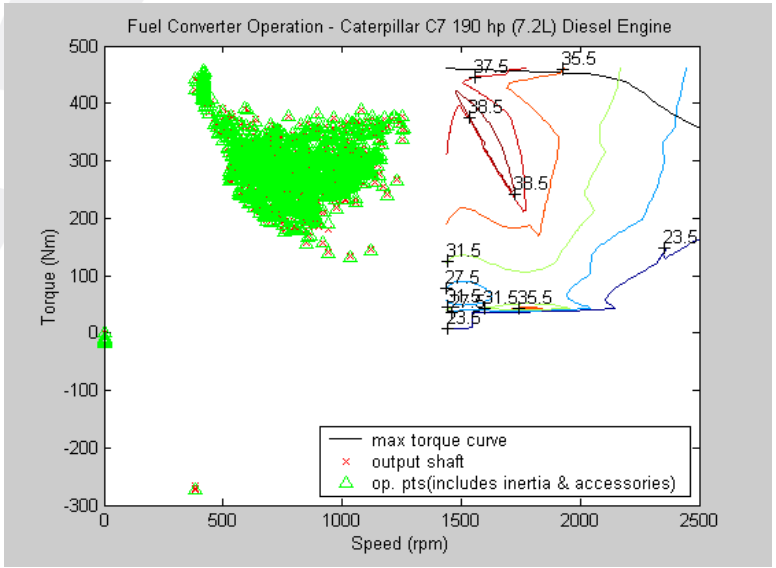


Results: What to Look For

Engine Operation



Conventional



Hybrid

Taken from ISA Design's ADVISOR Output Files

Results, Continued

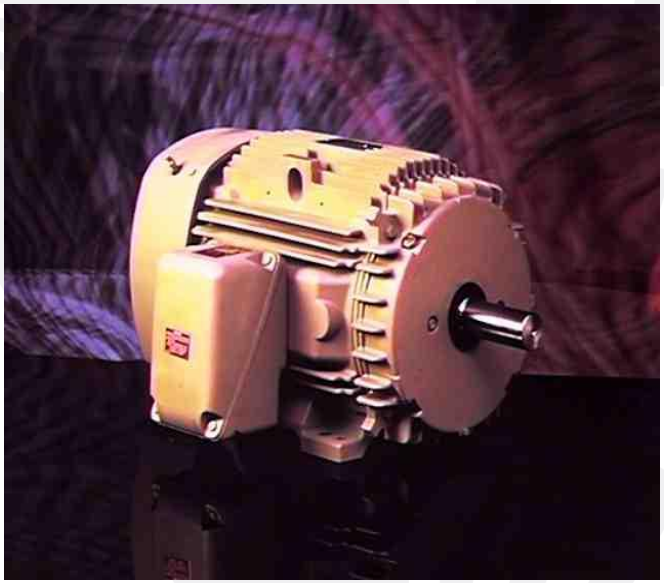
ARTERIAL Drive Cycle	Conv.	Retro.	Nu_dsn	ISA
Fuel Economy (mpg)	5	6.5	8	8.9
Fuel Efficiency Increase	0	30%	60%	78%

CBD14 Drive Cycle	Conv.	Retro.	Nu_dsn	ISA
Fuel Economy (mpg)	4.5	6.4	7.6	5.2
Fuel Efficiency Increase	0	42%	69%	16%

COMMUTER drive cycle	Conv.	Retro.	Nu_dsn	ISA
Fuel Economy (mpg)	6	7.4	8.1	10.1
Fuel Efficiency Increase	0	23%	35%	68%

Averaged Results	Conv.	Retro.	Nu_dsn	ISA
Fuel Economy (mpg)	5.2	6.8	7.9	8.1
Fuel Efficiency Increase	0	30%	52%	56%

Electric Motor



- **Model:** General Electric AP902
- **Application:** Automotive Duty
- **Phase:** Three Phase
- **Motor Type:** Severe Duty
- **Horsepower:** 100
- **RPM:** 3600
- **Volts:** 460
- **Hertz:** 60
- **Enclosure:** TEFC
- **Rotation:** CCW/CW
- **A_dim:** 20.8” (height)
- **C_dim:** 36.4” (depth)
- **Weight:** 1480 lb

Battery Selection

Lead Acid

- Shorter Life Span
- Deep Cycle
- Heavy
- Bulky
- Cheap

Nickel Metal Hydride

- Longer Life Span
- Lighter
- 5 times more expensive

Battery

- **Type:** Lead-Acid
- **Voltage:** 12V module
- **Rating:** 100 Amp Hours
- **Length:** 13.0"
- **Width:** 6.80"
- **Height:** 9.40"
- **Weight:** 75 lbs

Inverter

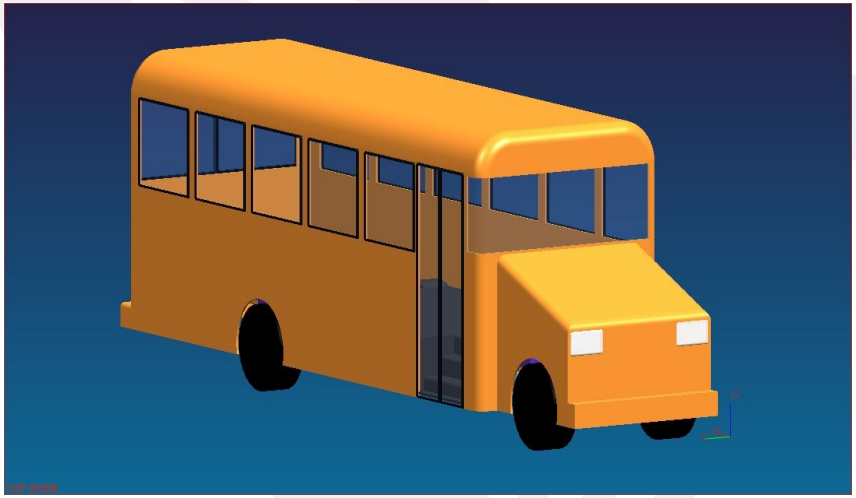
- **Model:** Saminco M1-250
- **Voltage Range:** 450V (min); 900V (max).
- **Power Rating:** 250kW @ 460V.
- **S/W Frequency:** Up to 10 kHz;
- **Temp:** -40 to 105 ºC.

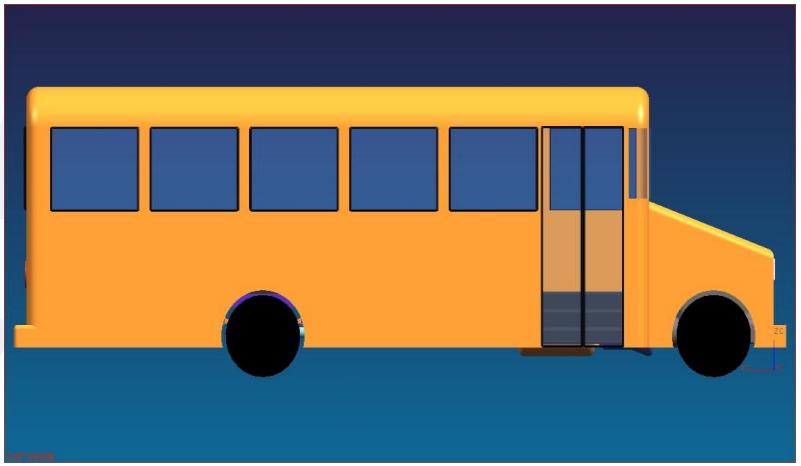
3D Modelling

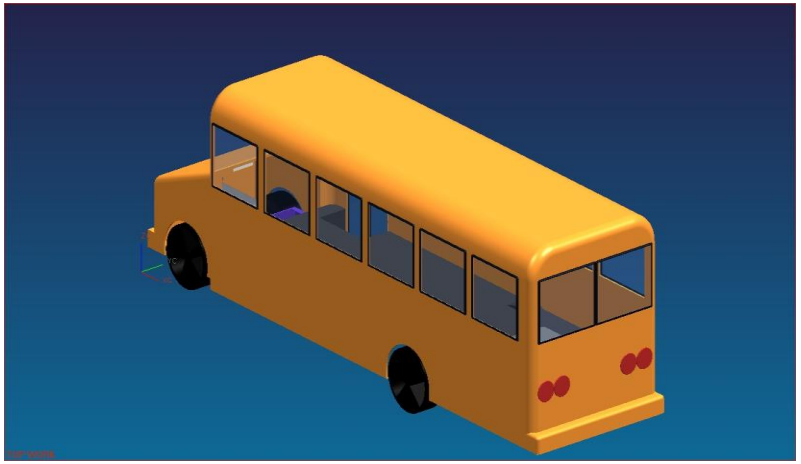
Purpose

- Expose mechanical engineers and aerospace engineers to solid modelling
- Provide visual representation of design
- Aids in determining components

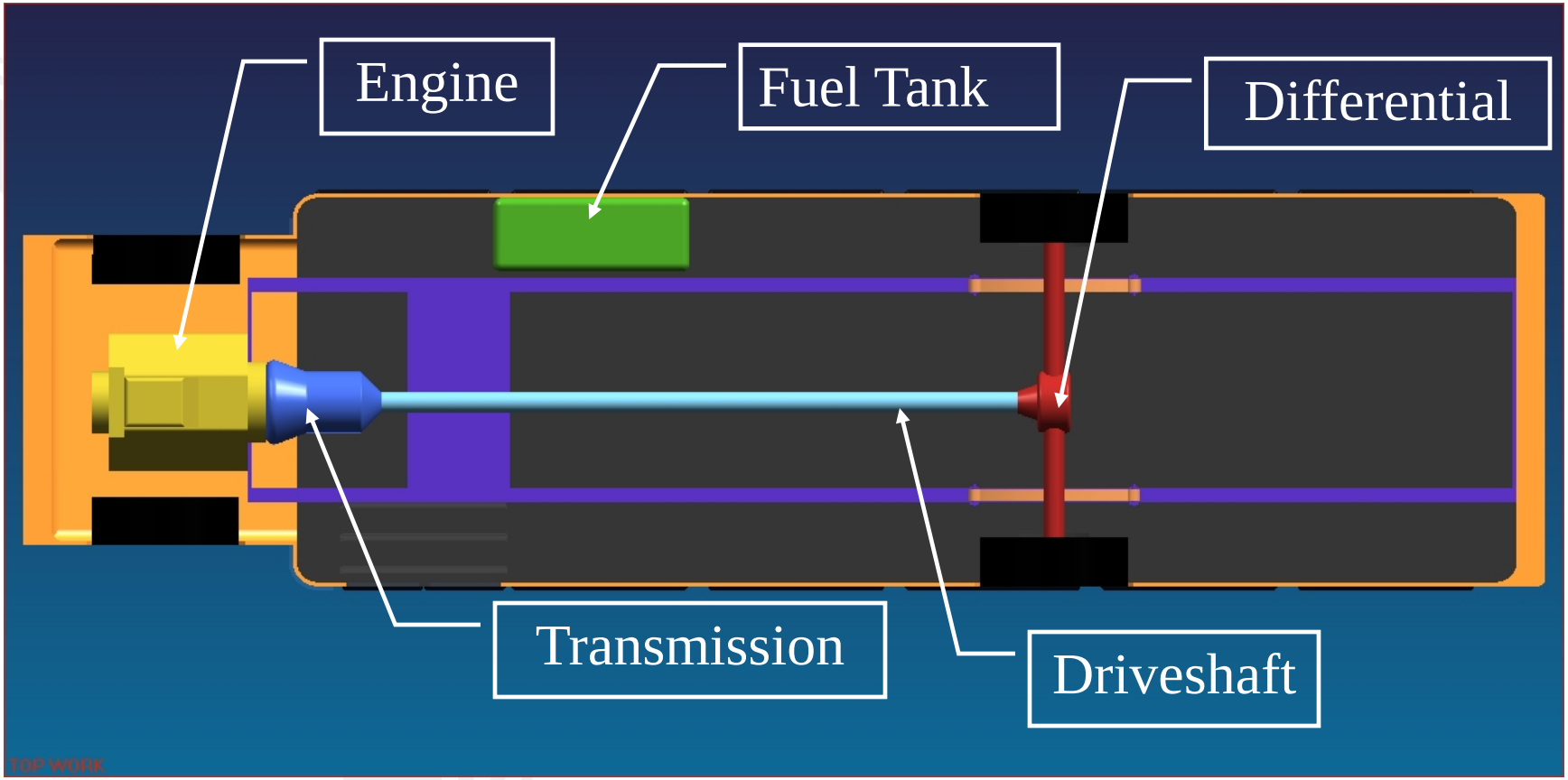
Blue Bird Vision Bus



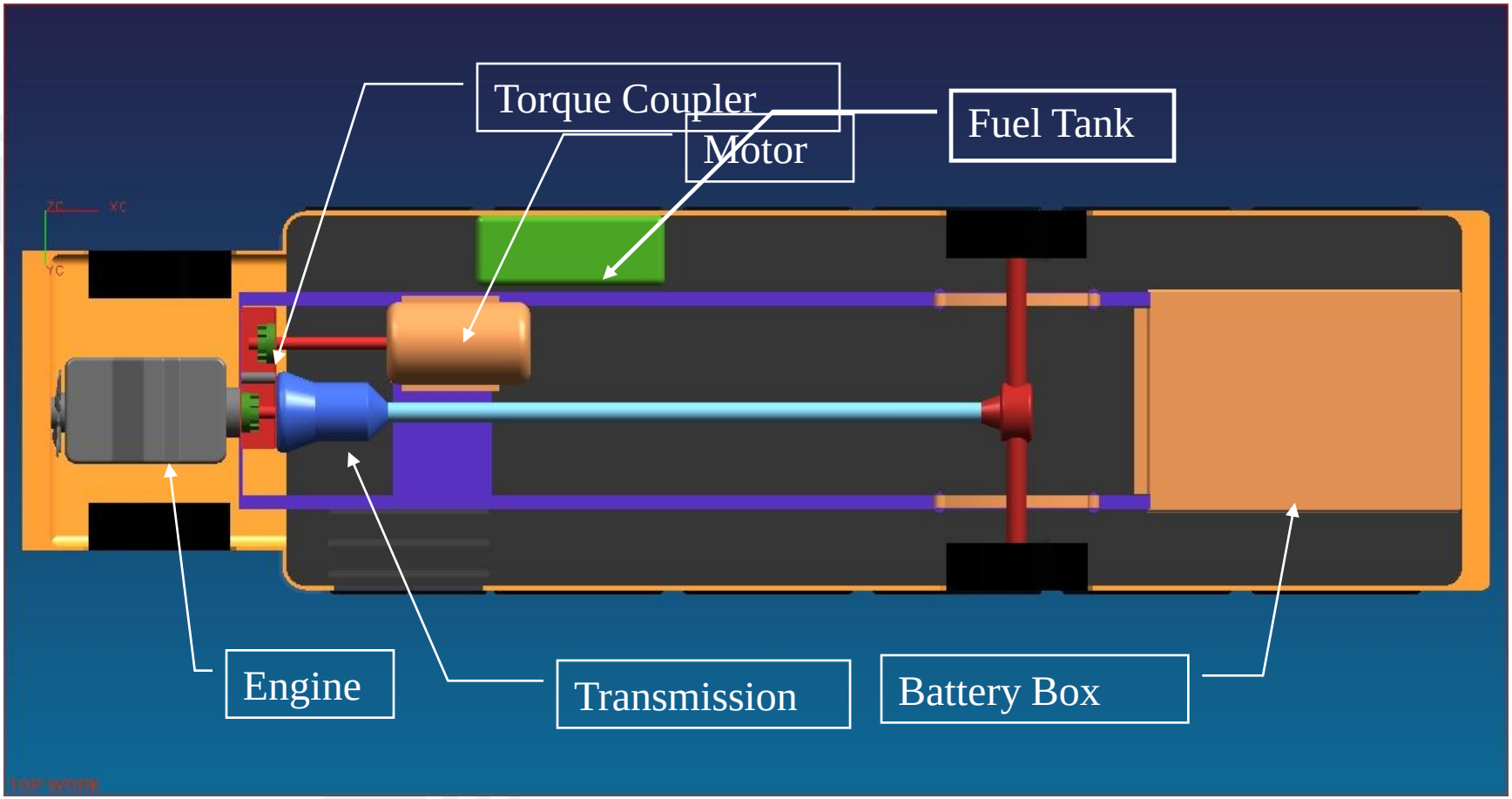




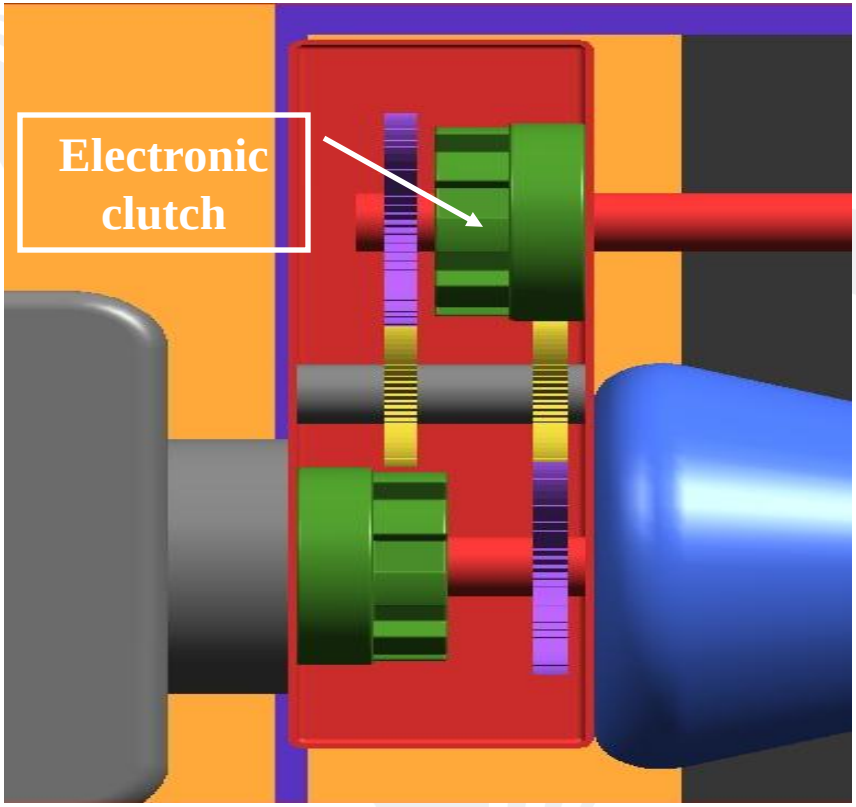
Conventional Configuration



Hybrid Configuration



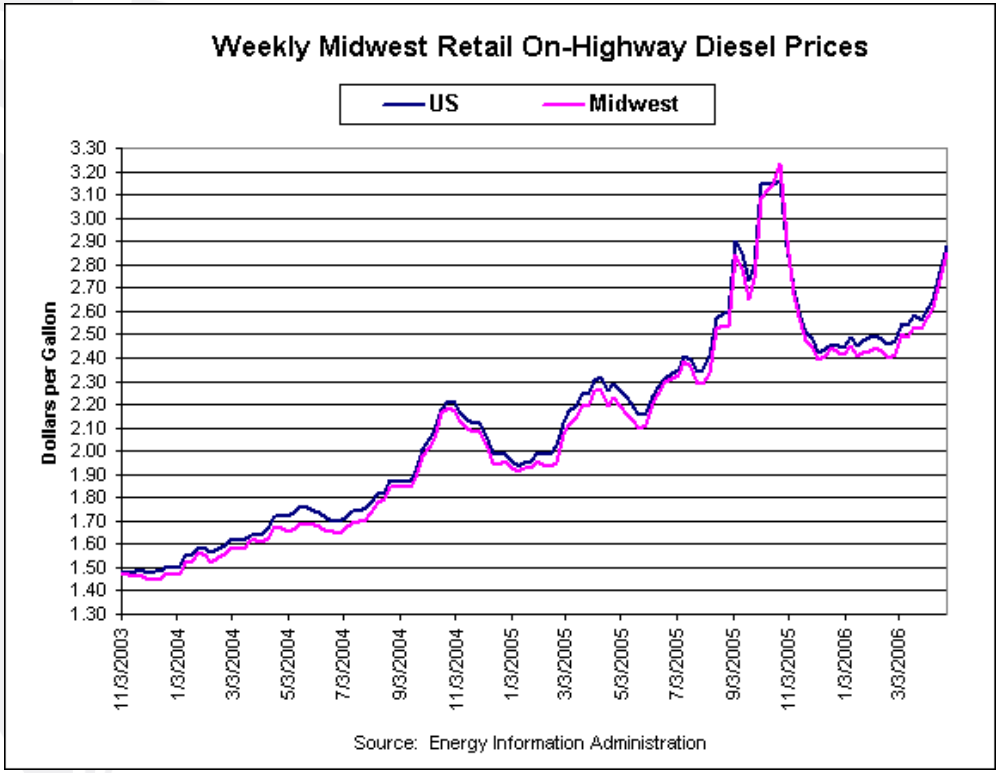
Torque Coupler



- Couples power from motor and engine.
- Provides separation of inputs.
- Works in Retrofit, New and ISA (Integrated Starter-Alternator) Designs.
- Enacting clutch allows motor to “kick-start” engine.

Fuel Cost Analysis

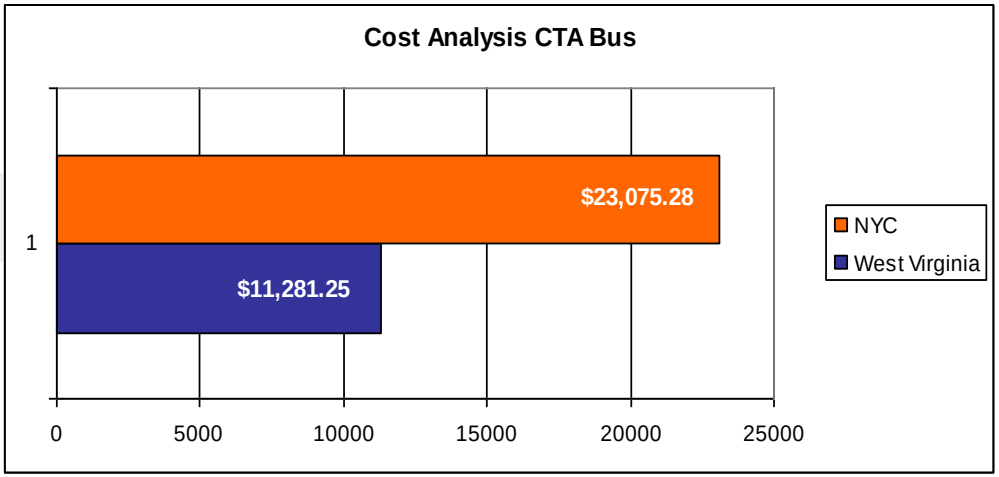
- Average cost of diesel fuel as of May 1, 2006, in the Midwest is $2.85 per gallon
- Prices have risen 12% from the year before and are projected to continue to increase in the future



Fuel Cost Analysis

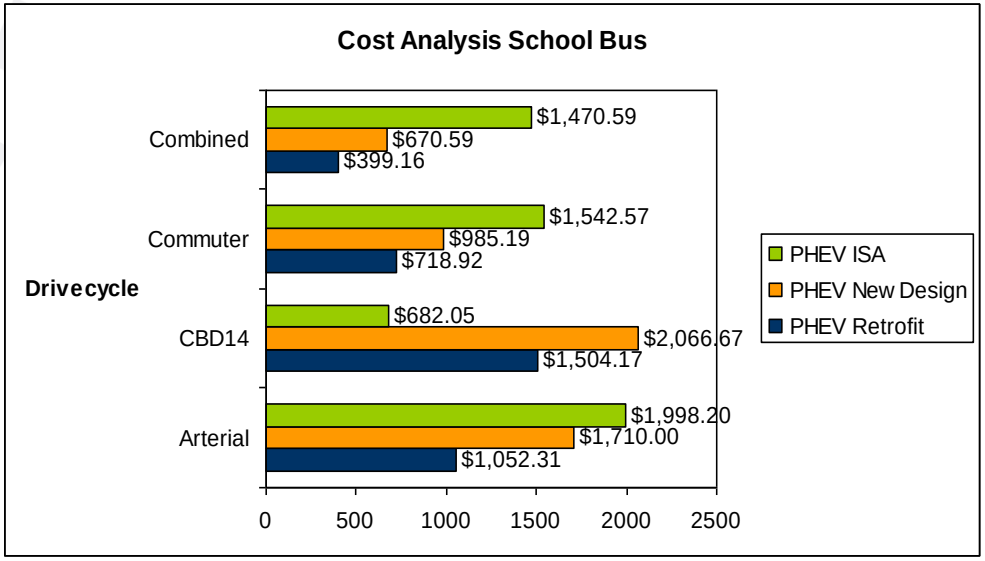
CTA Savings

- Savings of an average of $17,000 per bus per year
- Conversion of the entire fleet leads to a reduction of 7% of the budget



School Bus Savings

- Depending on the model used, and the drive cycle tested, varying amounts will be saved
- Greatest savings overall was seen in the parallel new design model



Conclusions

- The retrofit approach enables conversion of existing conventional buses to more efficient hybrid vehicles
- A new design allows us to downsize the engine making the overall system more efficient
- There was significant improvement in fuel economy for the CTA bus and school bus
- The 3D modelling helped in visualizing the mechanical system but was not precise enough to use for design
- As fuel rates continue to increase, the financial effectiveness of hybrids to grow

Future Work

- Propose retrofit to CTA as cost saving measure
- Present Blue Bird with project results
- Refine ADVISOR simulations and design
- Study emissions of hybrid buses
- Build prototype and revise design where necessary
- Explore plug-in HEV option
- Perform more in-depth cost analysis