

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

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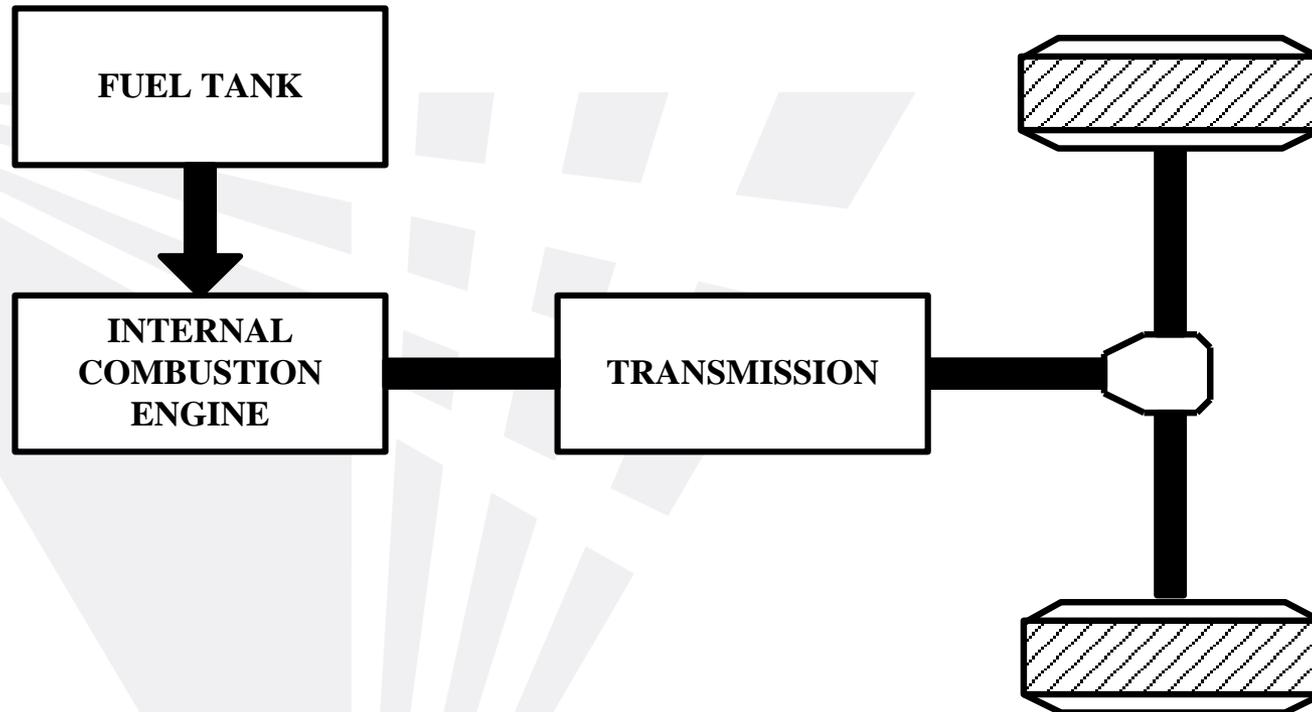
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URL: <http://www.iit.edu/~ipro342s06>

Presentation Outline

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

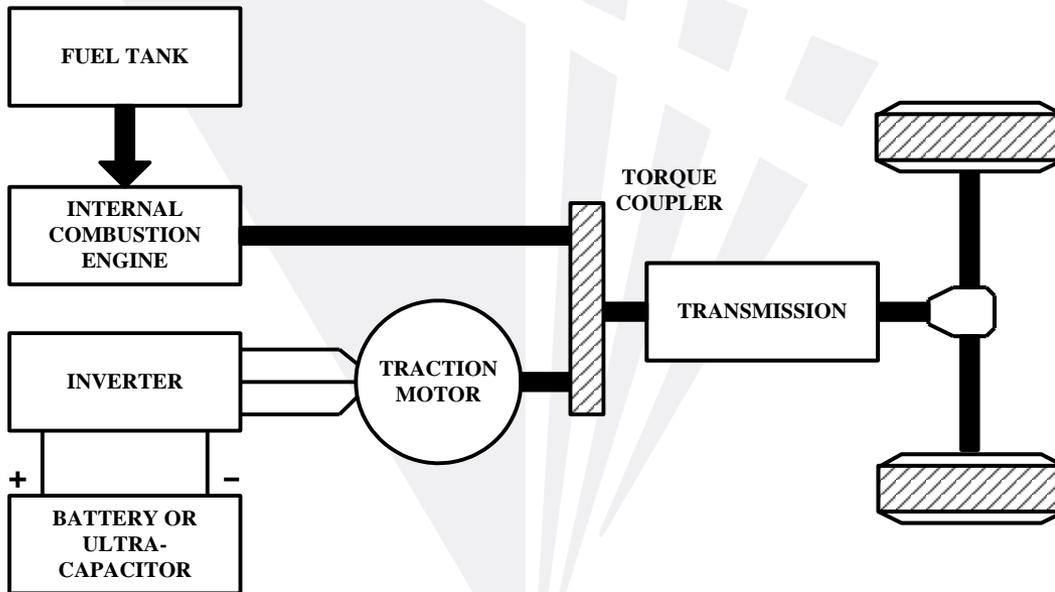
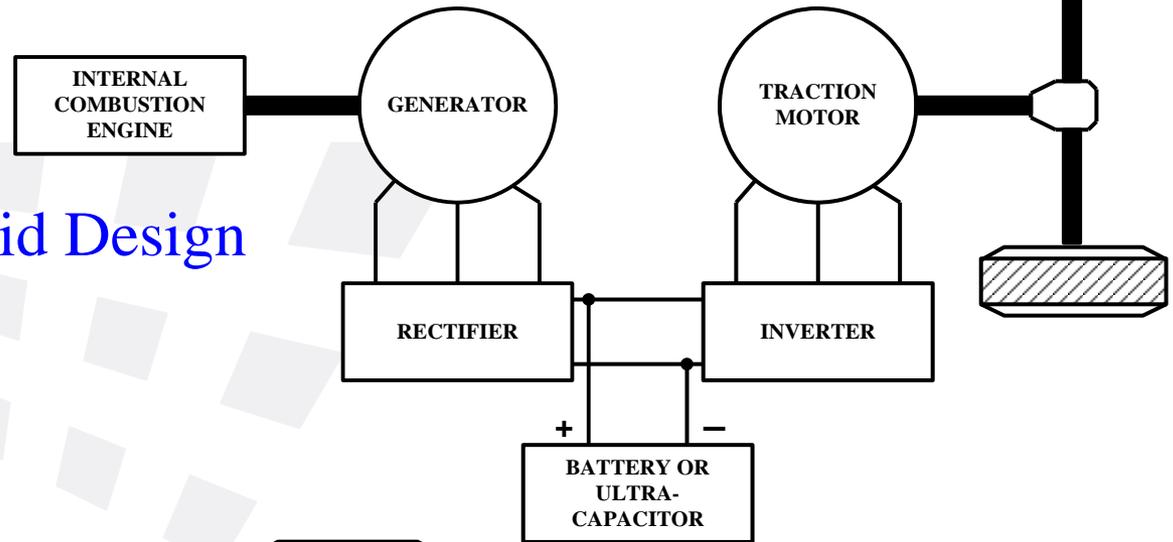
Conventional Vehicles



Maximum efficiency of 30 – 35 %

Hybrid Electric Vehicles

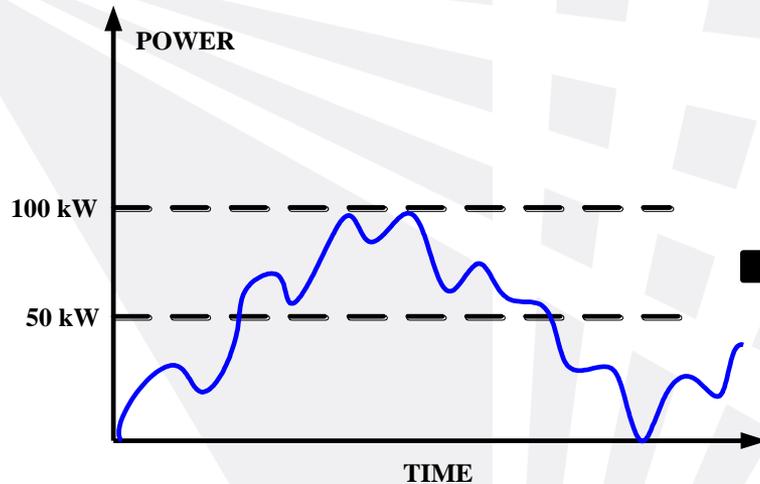
Series Hybrid Design



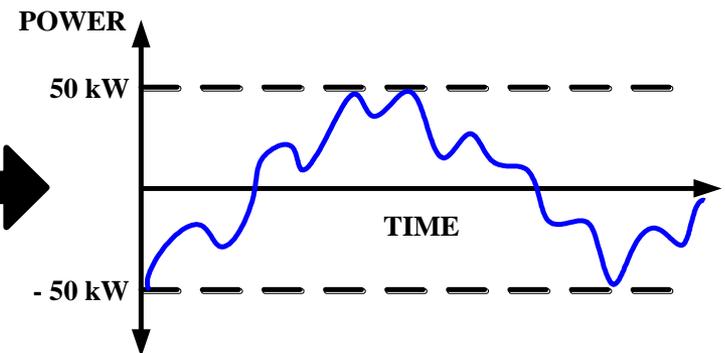
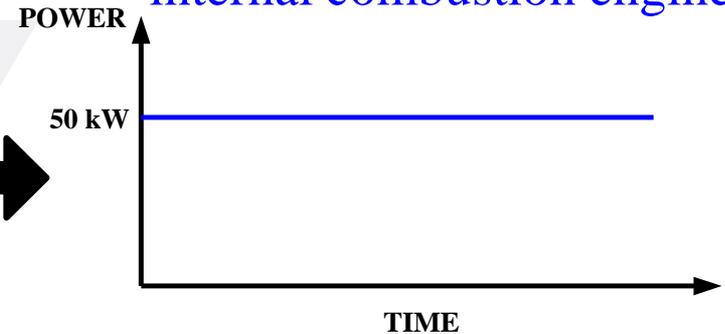
Parallel Hybrid Design

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

all_menus ▾

Start

Help

©
and
Disclaimer

Exit

Load Results



ADVISOR 2002

Advanced Vehicle Simulator

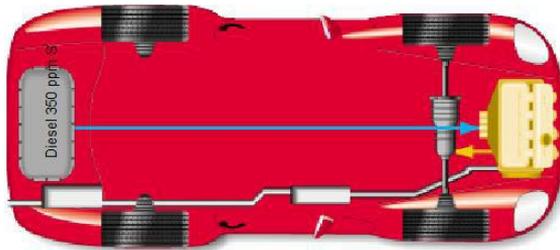


Units:

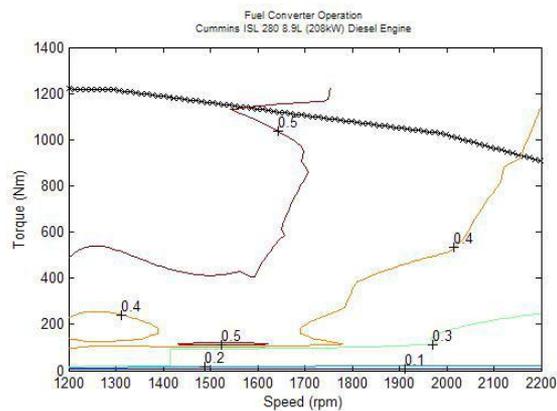
- Metric
- US

Simulating ADVISOR

Vehicle Input



Component Plot Selection
fuel_converter fc_efficiency



Load File: CTA_Conventional_in

Drivetrain Config: conventional

Component	version	type	max pwr (kW)	peak eff	mass (kg)
Vehicle	?	VEH_NOVA_1_modified			14663
Fuel Converter	ic	CTA_NOVA	214	0.4	710
Exhaust Aftertreat	?	EX_CI	#of mod	V nom	64
Energy Storage	?	ess_options			
Energy Storage 2	?	ess_2_options			
Motor	?	MC_ACT24_EV1_diaP			
Motor 2	?	motor_2_options			
Starter	?	starter_options			
Generator	?	gc_options			
Transmission	auto	TX_ZF5HP590AT_NOVA_2	0.85		114
Transmission 2	?	trans_2_options			
Clutch/Torq. Conv.	?	clutch/torque_converter_options			
Torque Coupling	?	TC_DUMMY			
Wheel/Axle	Cr	WH_HEAVY			0
Accessory	Const	ACC_HEAVY			
Acc Electrical	?	acc_elec_options			
Powertrain Control	conv	PTC_CONVAT5spd			

Auto-Size Scale Components

Cargo Mass: 136

Calculated Mass: 15687

override mass: 1

View Block Diagram: BD_CONVAT

Variable List:

Component: fuel_converter Edit Var.

Variables: fc_acc_mass 89.0711

Buttons: Save, Help, Back, Continue

Result Screens: How to Judge Success

Fuel Economy

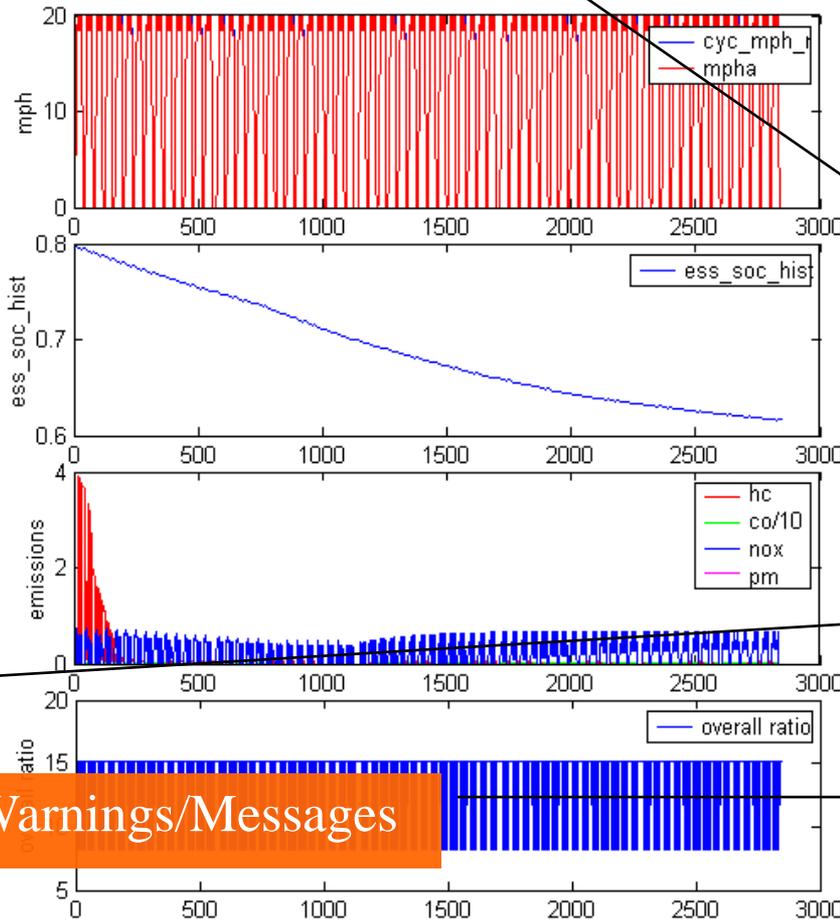
Drive Cycle

Battery SOC

Emissions

Energy Use and Output Plots

Warnings/Messages



Results figure

Componer: fuel_converter [plot control]

Plot Variable (Select Axis): fc_brake_trq [?] # of plots: 2

Fuel Economy (mpg)	6.4
Gasoline Equivalent	4.9
Distance (miles)	9.9

Emissions (grams/mile) Standards			
HC	CO	NOx	PM
22.331	0.502	63.526	0

Acceleration Test

0-60 mph	n/a	Max. Accel.	n/a
40-60 mph	n/a	Distance in 5s (ft)	n/a
0-85 mph	n/a	Time in 0.25mi (s)	n/a
		Max. Speed (mph)	n/a

Gradeability: n/a %

Energy Use Figure [Output Check Plots]

Compare Results With: Sim Data [Test Data]

Warnings/Messages: none

[Replay] [Back Two] [Help] [Back] [Exit]

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

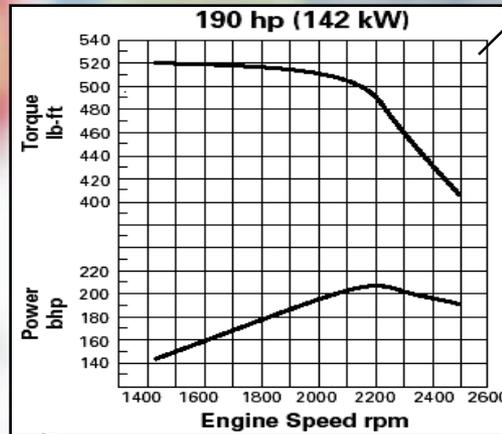
Conventional Vehicle Specifications

< 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



VEH_BB_Vision
 FC_CI190_Cat_C7 153 0.39
 EX_CI

BB_Vision_TX_PTS2500

WH_HEAVY

ACC_HEAVY

PTC_CONVAT5spd

< 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

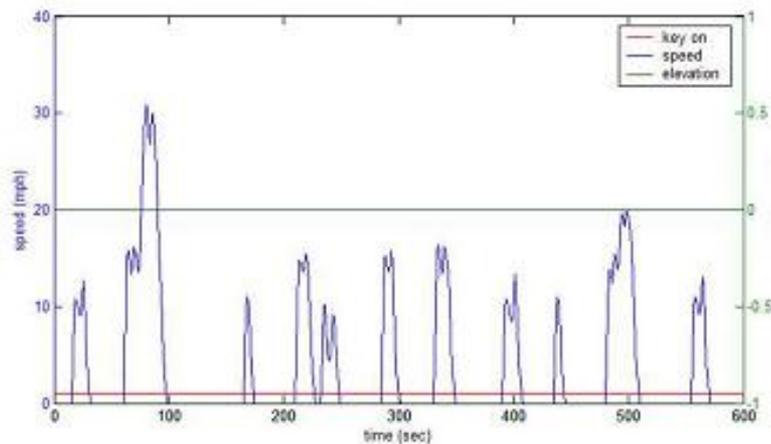


Fig.3 New York Bus Drive Cycle

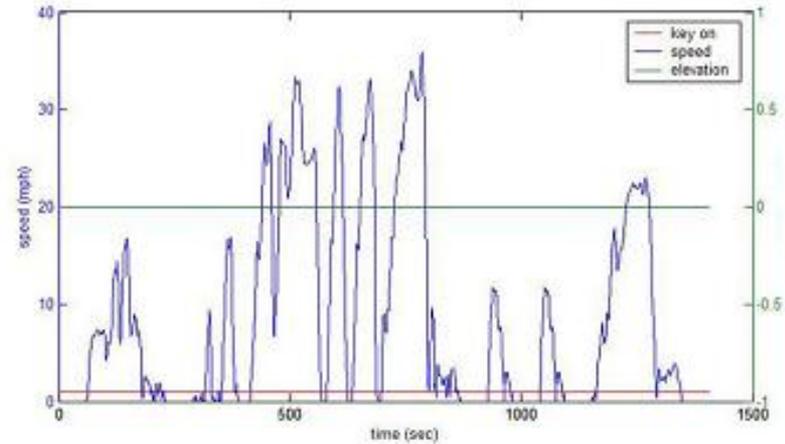


Fig. 4 West Virginia City Bus Drive Cycle

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**

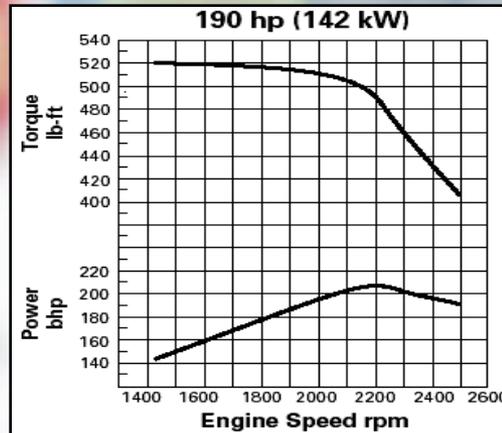


ADVISOR Customization

< 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 m²

Conventional Vehicle Specifications



< 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

VEH_BB_Vision
 FC_CI190_Cat_C7 153 0.39
 EX_CI

BB_Vision_TX_PTS2500

WH_HEAVY

ACC_HEAVY

PTC_CONVAT5spd

Parallel Retrofit Specifications

Batteries:
(85 Ah)

ESS_PB85 36 430

Electric Motor
(75 kW)

MC_AC75 75 0.92

Torque Coupler

TC_DUMMY

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

Parallel New Design Specifications

Down-sized Engine
(90 kW)

FC_CI190_Cat_C7 90

Batteries:
(85 Ah)

ESS_PB85 42 501

Electric Motor
(70 kW)

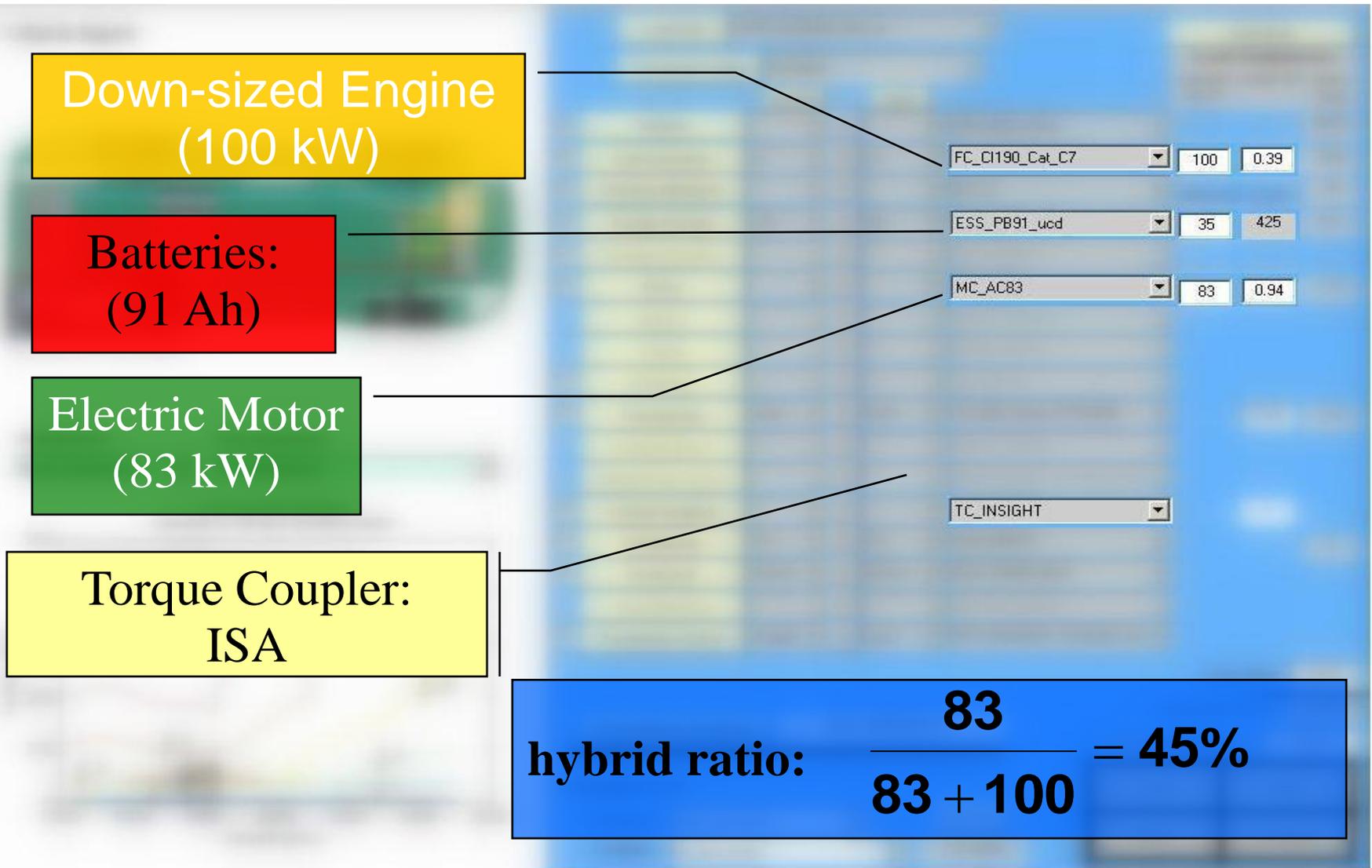
MC_AC75 70 0.92

Torque Coupler

TC_DUMMY

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

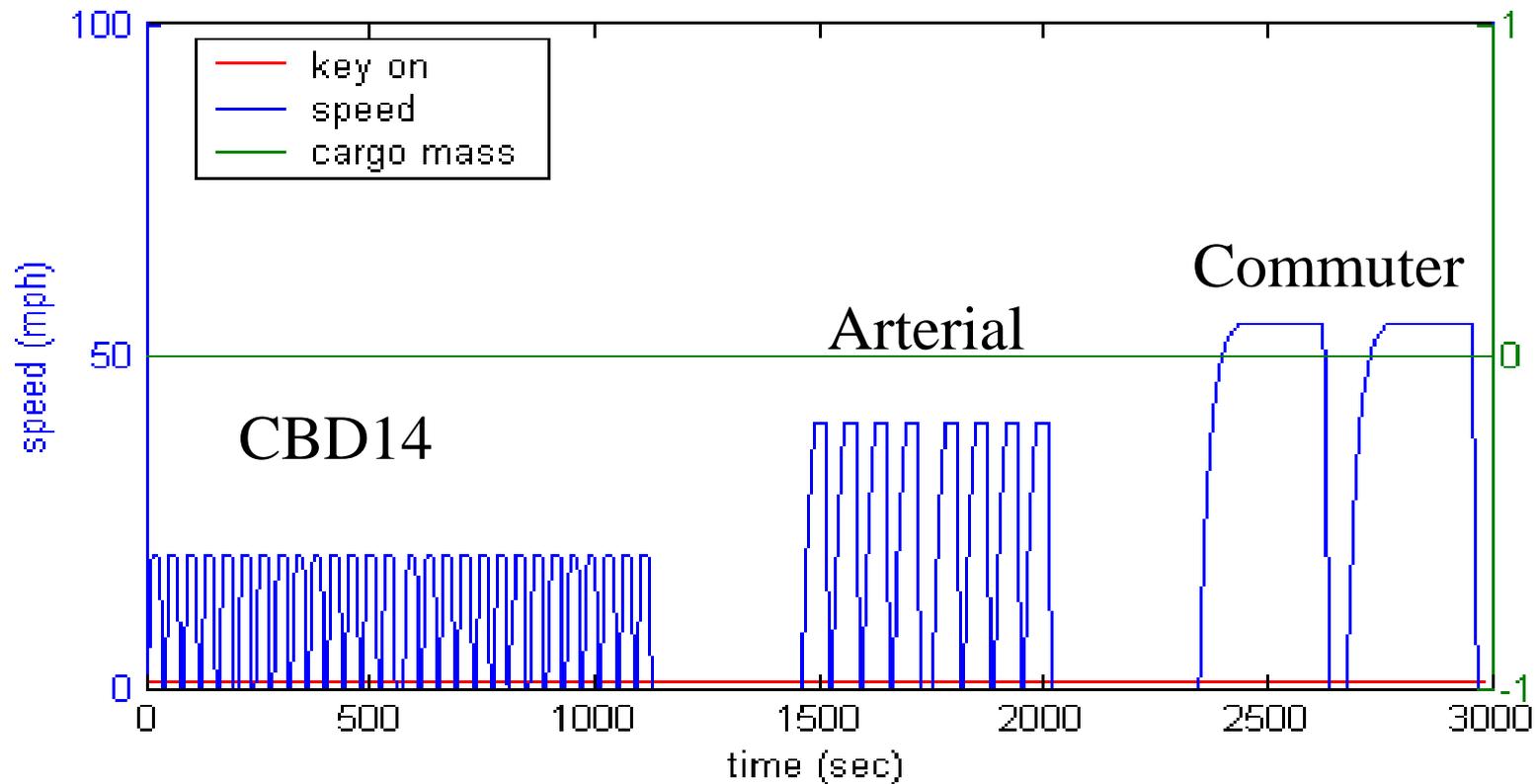
Parallel Integrated Starter-Alternator Design Specifications



Test Procedures: How to Measure Performance

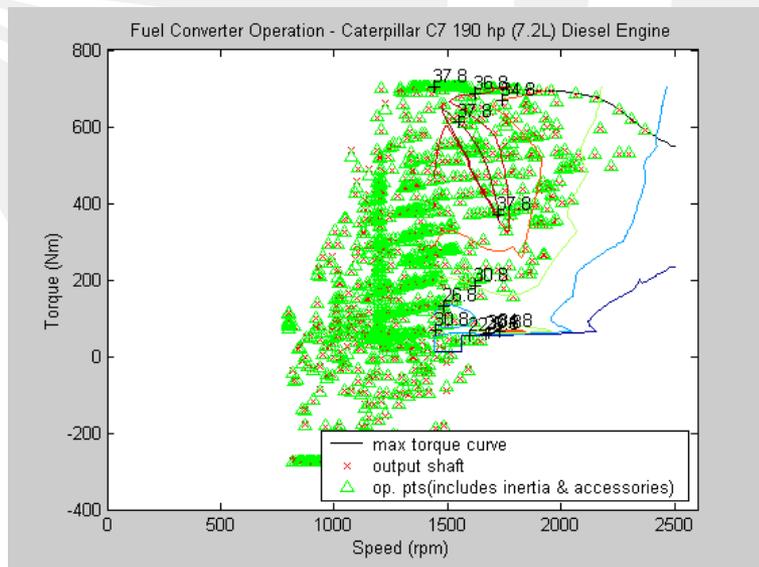
Drive Cycles

- CBD14
- ARTERIAL
- COMMUTER

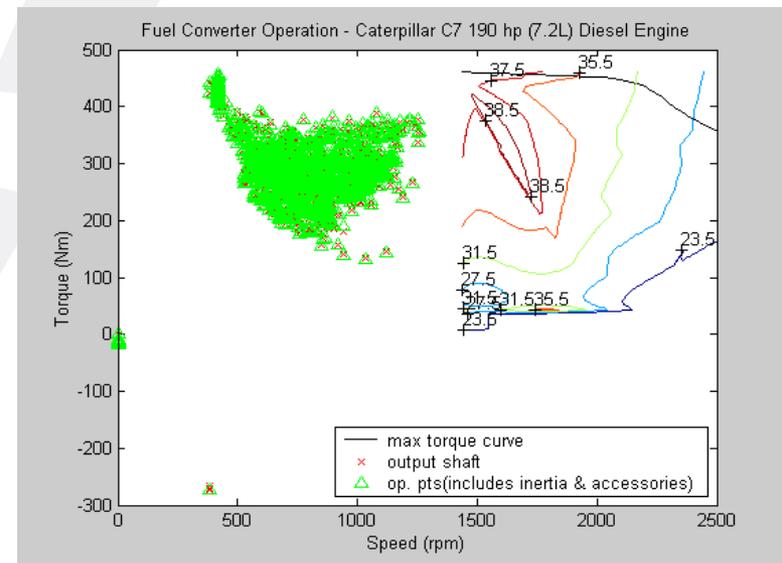


Results: What to Look For

Engine Operation



Conventional



Hybrid

Taken from ISA Design's ADVISOR Output Files

Results, Continued

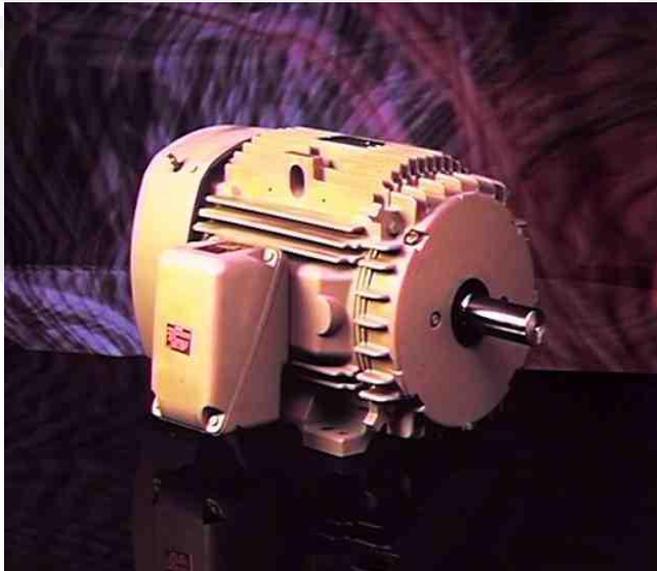
ARTERIAL Drive Cycle	Conv.	Retro.	Nu_dsn	ISA
Fuel Economy (mpg)	5	6.5	8	8.9
Fuel Efficiency Increase	0	30%	60%	78%

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

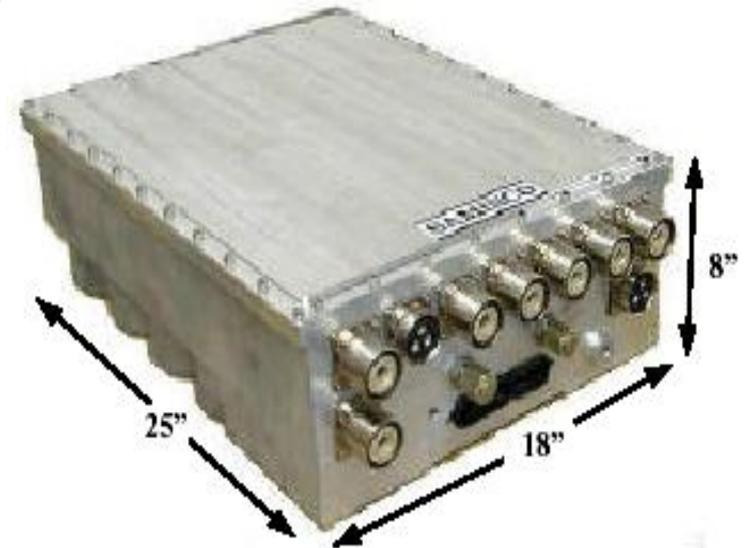
Battery

- **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 °C.

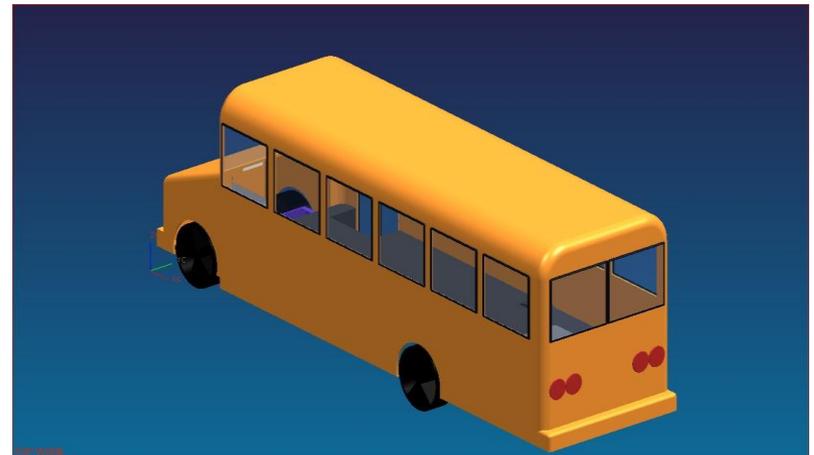
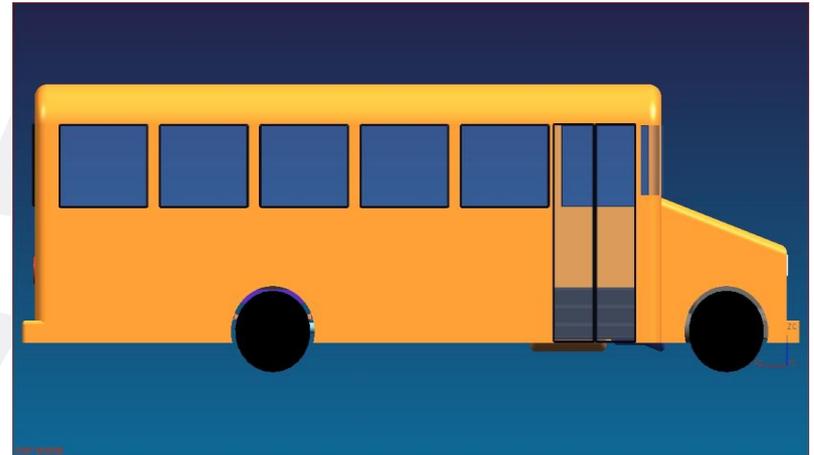
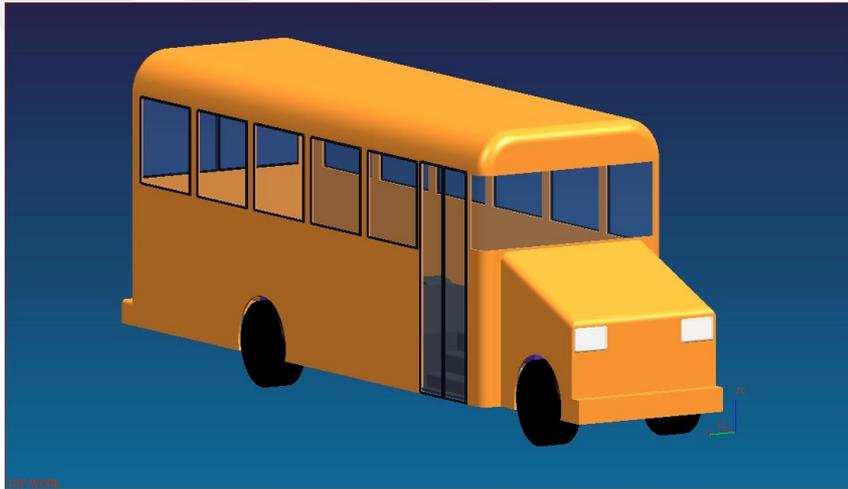


3D Modelling

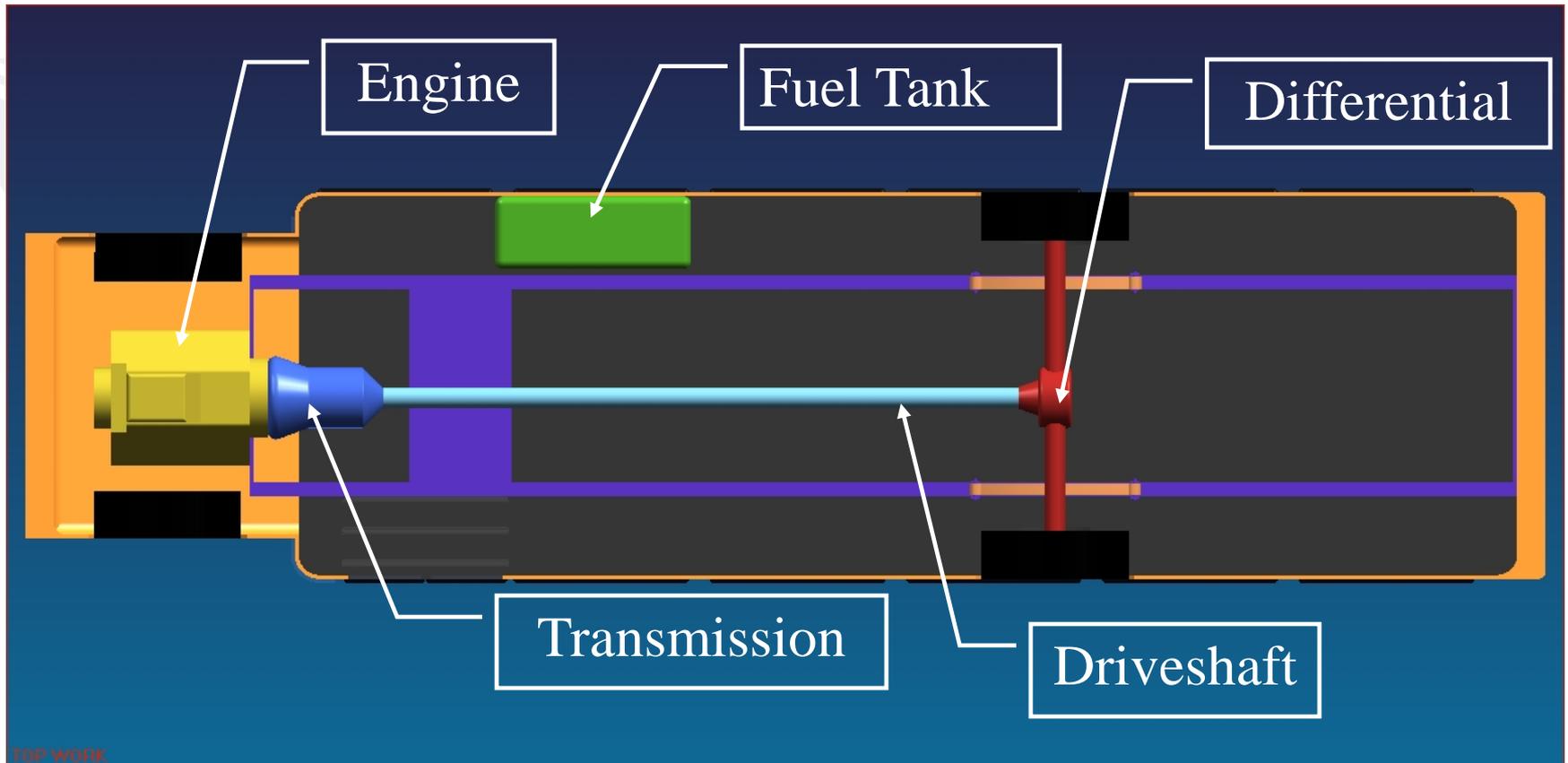
Purpose

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

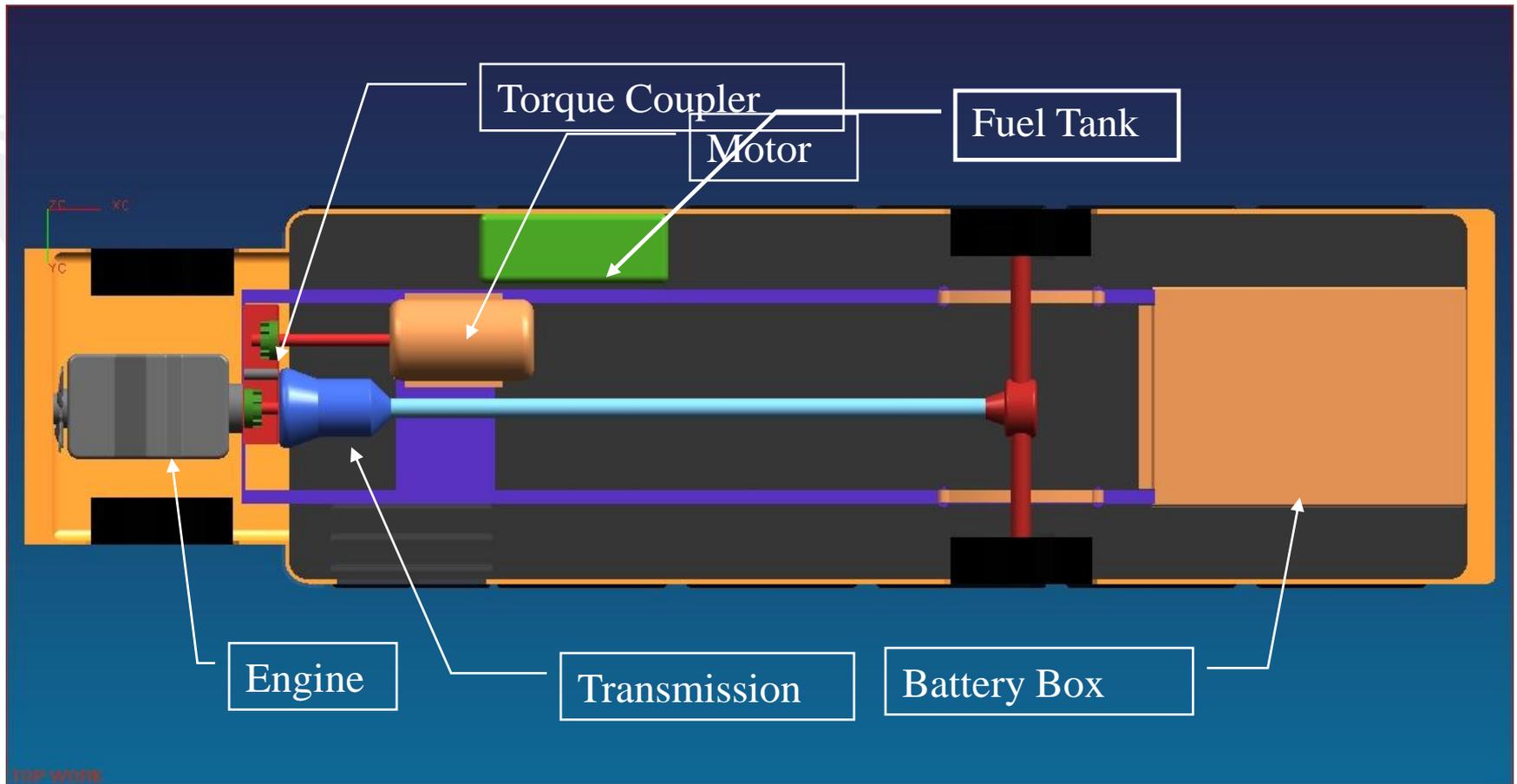
Blue Bird Vision Bus



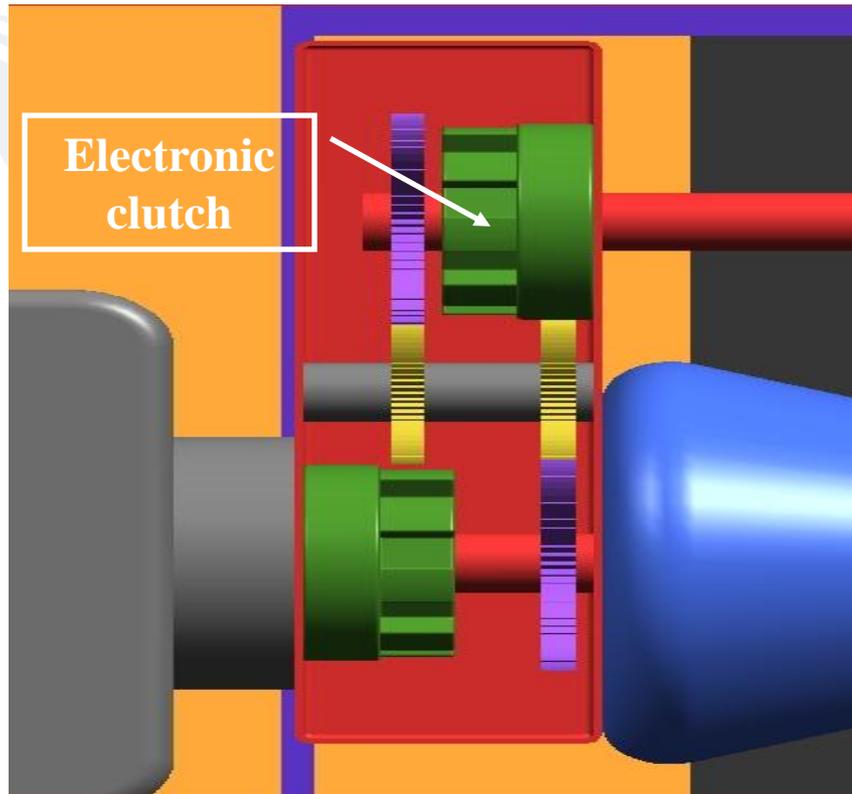
Conventional Configuration



Hybrid Configuration



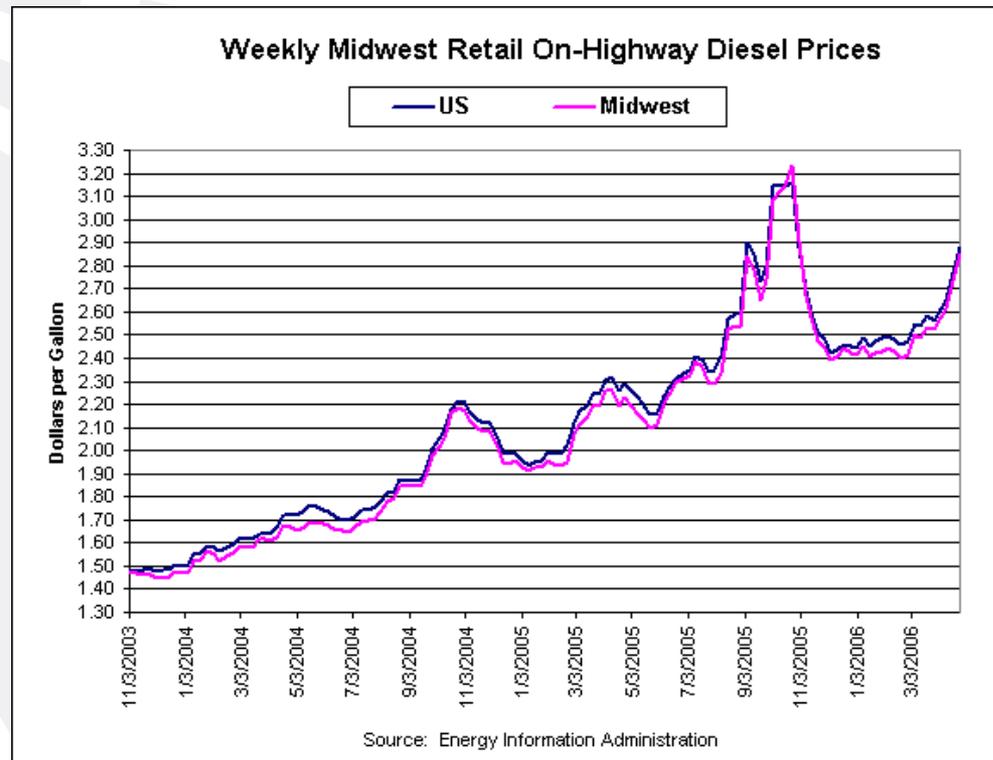
Torque Coupler



- 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

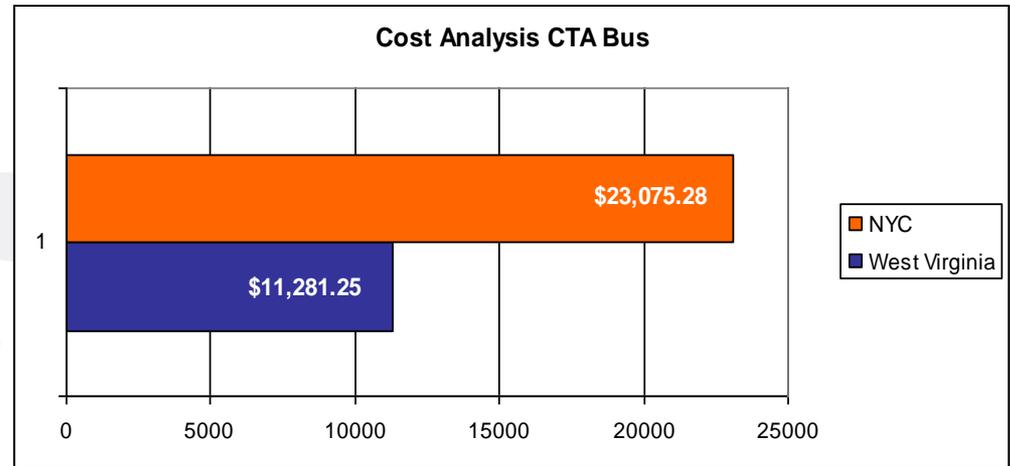
- Average cost of diesel fuel as of May 1, 2006, in the Midwest is \$2.85 per gallon
- Prices have risen 12% from the year before and are projected to continue to increase in the future



Fuel Cost Analysis

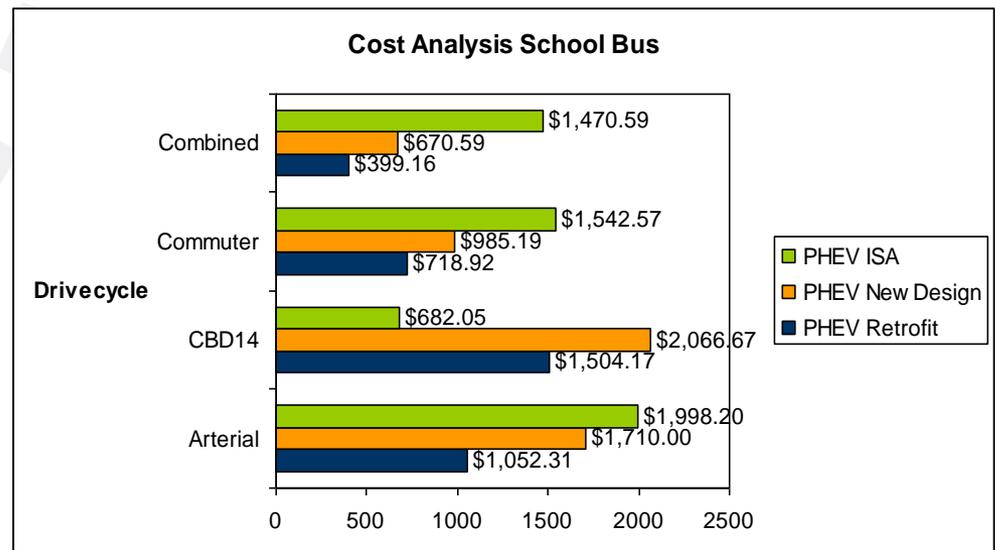
CTA Savings

- 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**