



Hybrid Refuse Truck Study

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Introduction/Problem Definition



Introduction:

- Fuel economy benefits of a hybrid vehicle are highly dependent on
 - Vehicle duty cycle
 - Component performance
 - Integration and control of the powertrain and vehicle systems
- Refuse collection trucks have a remarkably varied drive cycle
- Refuse truck fuel economy improvements may have significant impact: estimated 66,000 trucks accumulating an average of 23,350 miles annually.

Problem Definition: Investigate the potential for fuel economy improvement of a refuse truck in an urban cycle using hybrid powertrains. Powertrain architectures examined:

- Conventional powertrain.
- Hydraulic hybrid.
- Parallel electric hybrid.
- Series electric hybrid.



Analysis-Approach



Apply range of tools & techniques to efficiently develop concept powertrain.

Approach:

- Clarify characteristics of real-world mission by vehicle measurements.
- Establish system architectures and performance requirements.
- High-level analysis.
 - Energy assessment for bounding expectations, providing focus.
 - Preliminary sizing to meet requirements.
- High-fidelity simulations.
 - Short, representative cycle for initial system integration, sizing refinements.
 - Confirm over alternative cycles, including measured vehicle mission.



Analysis-Vehicle Requirements

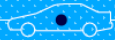
Data logged during refuse truck operation over 1 day in UK using GPS-based data acquisition system



Refuse Truck Cycle Statistics	
Duration	8.42 hr
Average Speed	11.6 mph (18.6 kph)
Number of Stops	459
Truck idling portion	40.1%
Ave propulsion wheel power (accessories, PTO not included)	13.1 kW
Refuse collected	25,250 kg
Trips to landfill	2

Vehicle requirements at G.V.W. (26,000 kg):

- Sustained top speed \geq 60 mph.
- Startability on 20% grade at \geq 5 mph for 300 ft.
- Sustained gradeability on 0.5% grade at \geq 55 mph.
- Hybrid acceleration must match or improve on conventional powertrain.



Analysis-Ricardo Libraries For MSC.EASY5



Ricardo is developer of 4 commercial libraries for MSC.EASY5, partnering with MSC.EASY5 since 1994:

- Powertrain / Powertrain Basic
- Engine
- Fuel Cell
- Electric Systems

Flexible - over 150 automotive-related simulation components:

- Diesel, gasoline, gaseous-fueled engines and fuel cells
- On & off-highway ground vehicles
- Hybrids and other specialty applications

Realistic modeling of complex, non-linear behavior of systems including mechanical, hydraulic, electrical, control elements

Virtual vehicle modeling with co-simulation

Powertrain and Engine Libraries used

for this application.



Analysis-Ricardo Libraries For MSC.EASY5

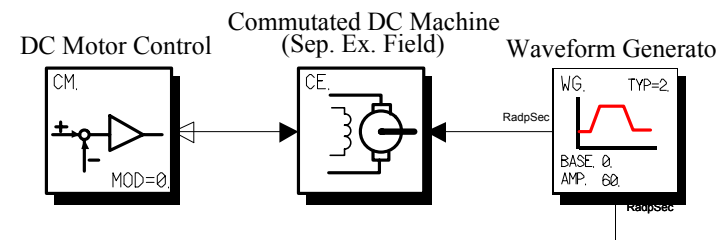


Powertrain Library

- Library of common powertrain & vehicle elements.
- Typical applications:
 - Performance prediction (e.g. acceleration, gradeability, fuel consumption, cycle time)
 - Preliminary evaluation of driveability (e.g. response to terrain or operator input)
 - Torsional characteristic assessment
 - Engine and driveline control strategy development
 - Estimation of dynamic loads (mechanical, clutch thermal loads)

Electric Systems Library

- Library of common electrical elements.
- Typical applications;
 - Hybrid vehicle powertrains.
 - Electrically-driven accessories.
 - Electric assist turbocharger or electric turbocompounding.





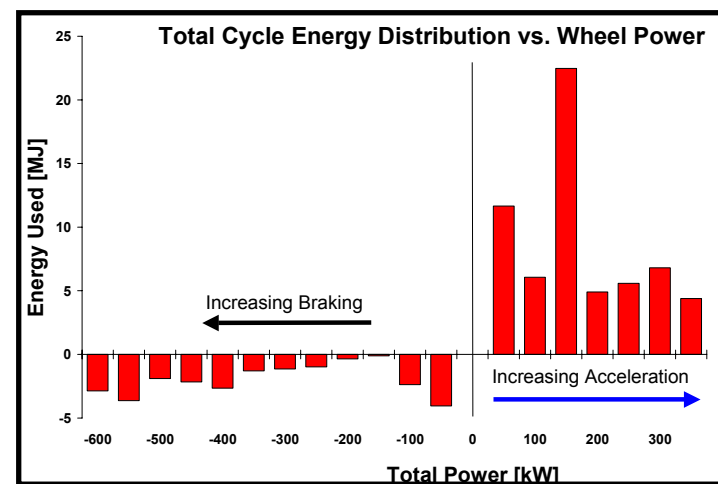
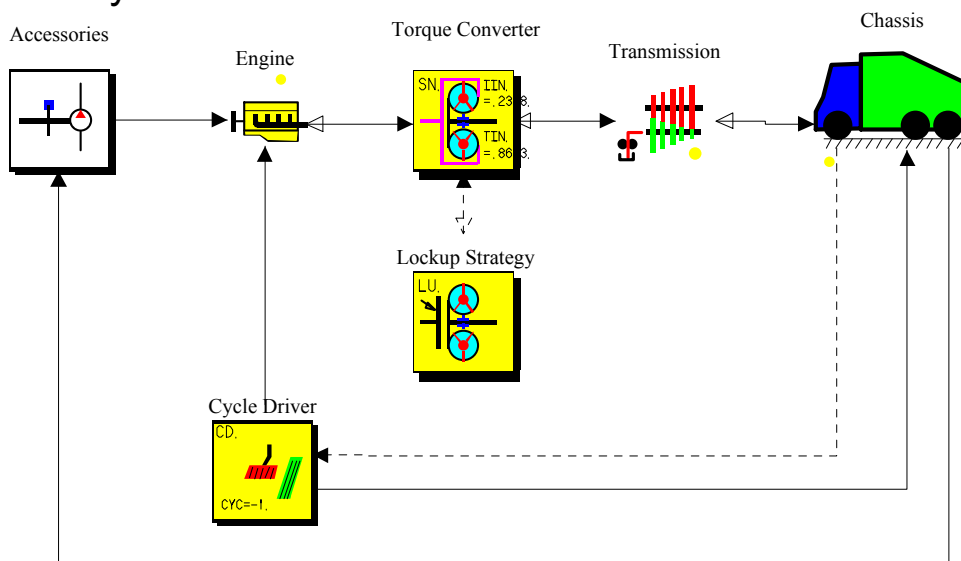
Analysis-High Level

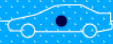


Prior to detailed simulation, a high level series of analyses were undertaken to:

- Provide initial component sizing
- Evaluate regenerative braking potential to assess viability of hybridization

Analyses utilized Baseline model constructed using MSC.EASY5 Ricardo Powertrain Library:



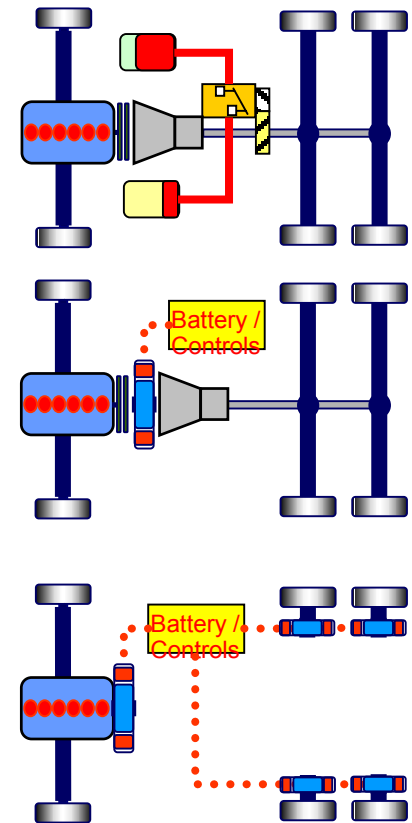


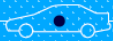
Analysis-Subsystem Design

Based on high level analysis, the following subsystems were sized to meet vehicle performance requirements:

- Diesel Engine
 - Engine for conventional architecture sized to meet peak requirements.
 - Hybridization allows diesel to be sized for sustained requirements, allowing smaller, more efficient engines.
- Electric Hybrid Components
 - Selected NiMH battery technology
 - Selected brushless DC motor technology
 - Parallel sized for regenerative braking
 - Series sized for peak output requirements
- Hydraulic Hybrid System
 - Selected an open system operating to 6000 psi
 - Sized for regenerative braking

Further refinement and sizing as well as controls strategy development conducted during detailed system simulation

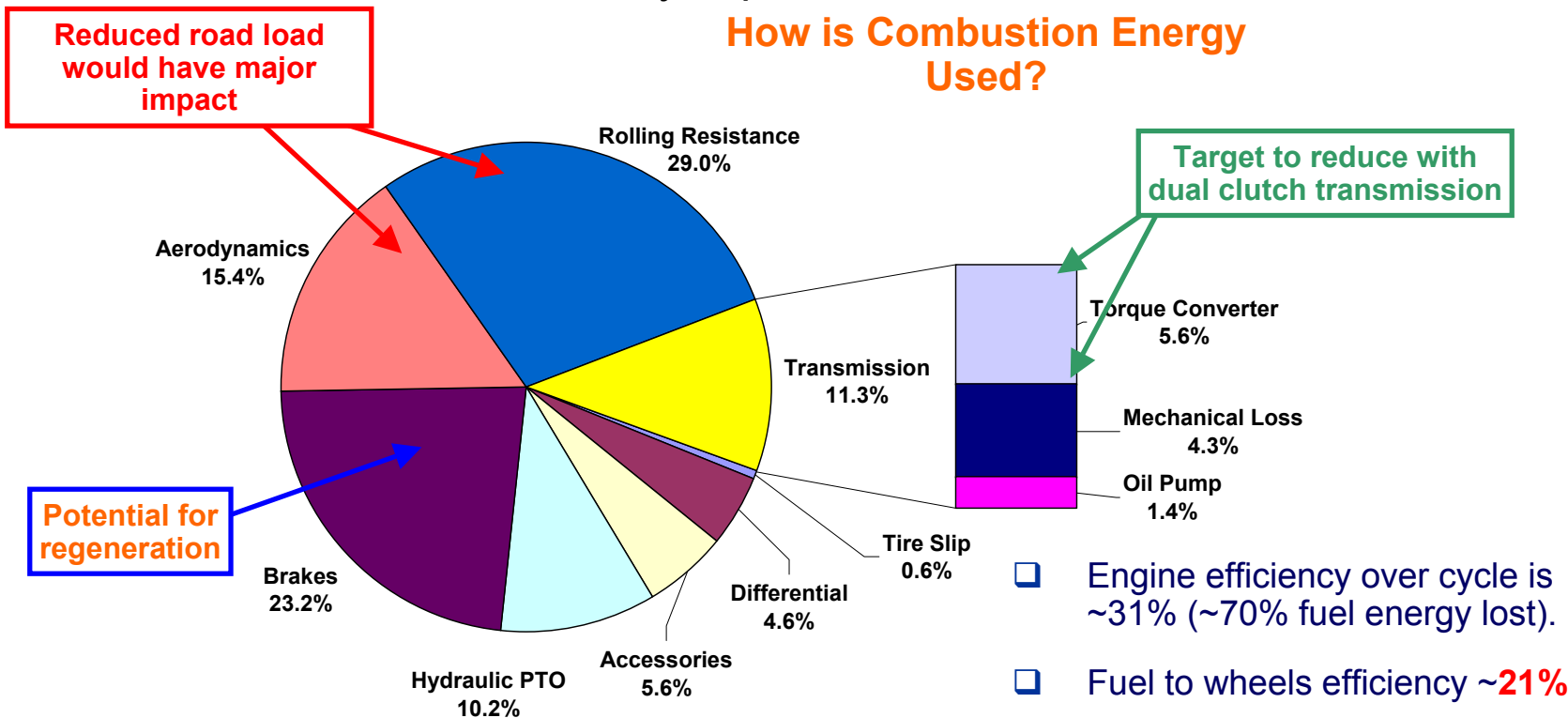


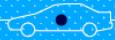


Analysis: Energy Audit



MSC.EASY5 simulation of baseline vehicle provided detailed information on system losses to focus fuel economy improvement efforts:

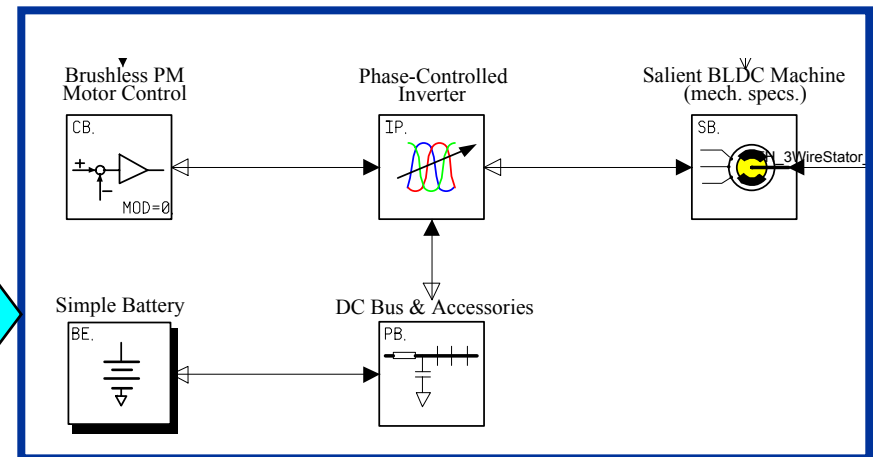
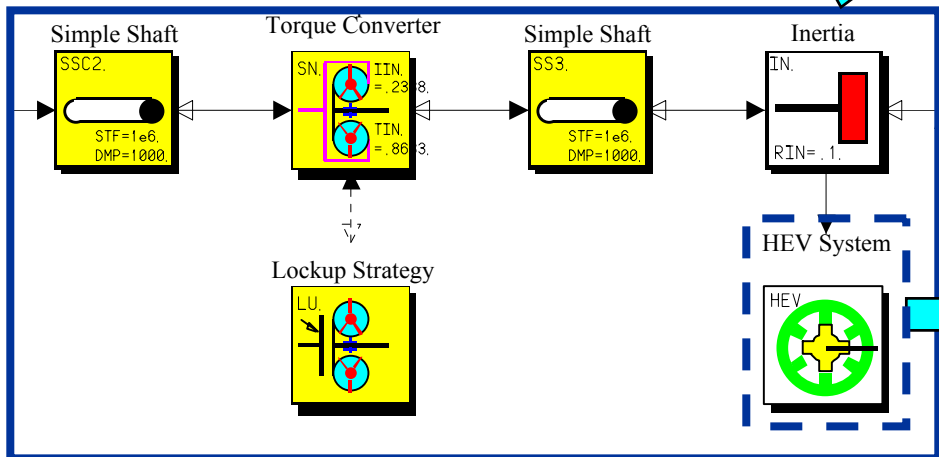
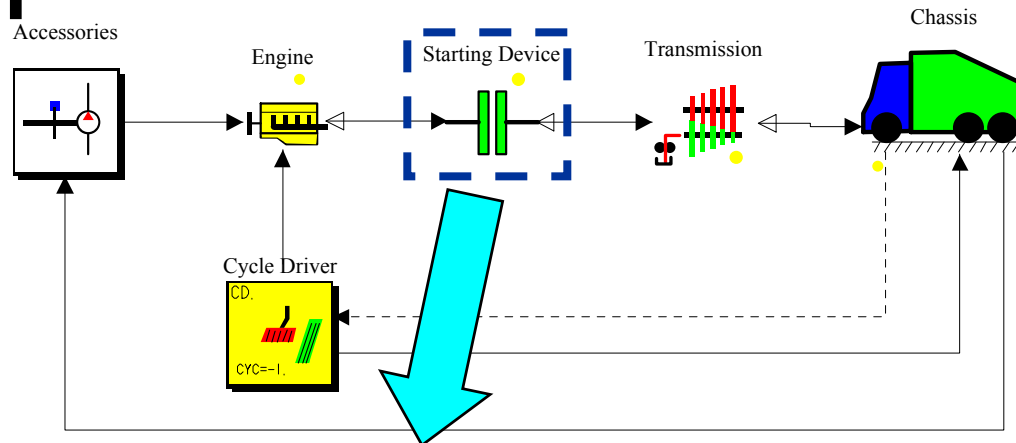




Analysis-Detailed System Simulation



Complex Models built from baseline MSC.EASY5 model



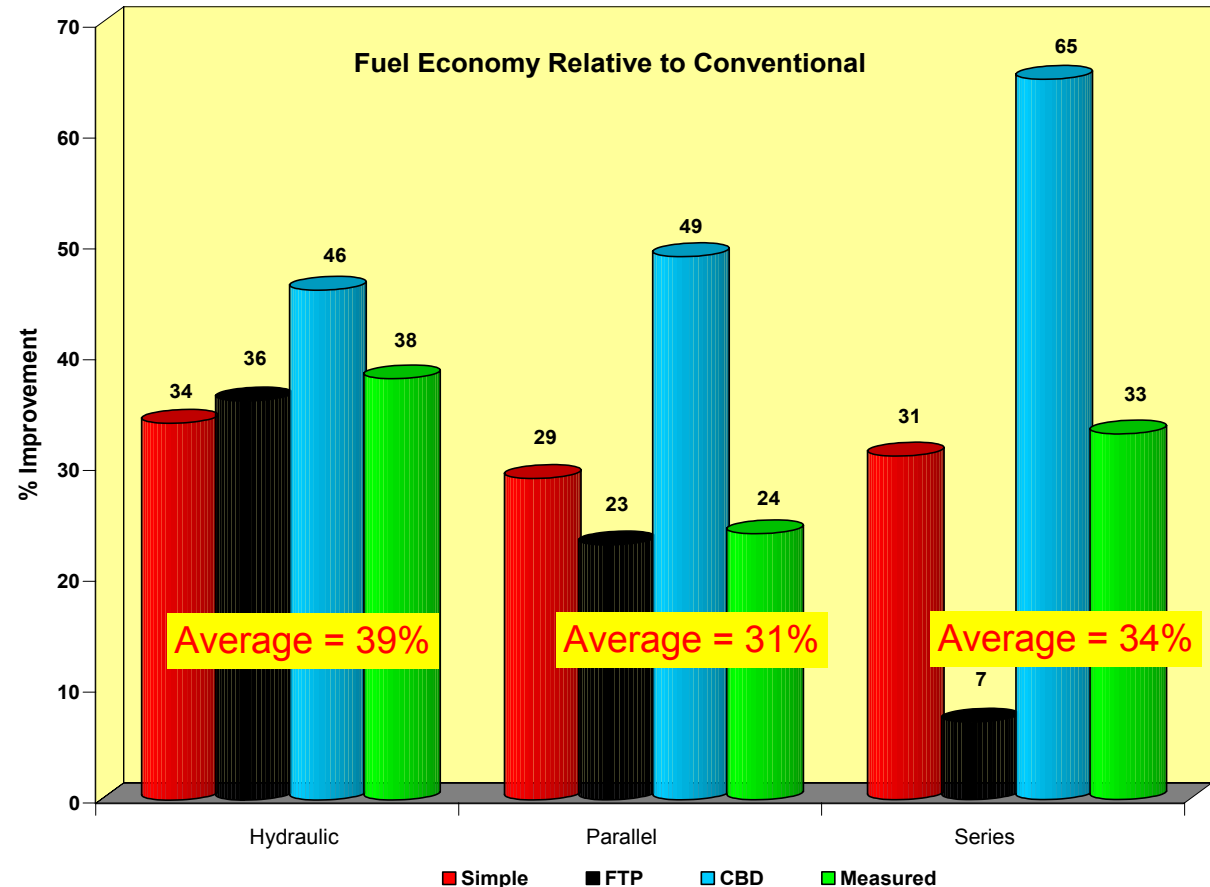
PRODUCT DEVELOPMENT CONFERENCE

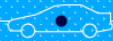


Results – Fuel Economy



Drive Cycle	Comments
Simple	Simple geometric cycle with characteristics similar to measured cycle.
FTP*	Higher speed cycle targeted at light duty automotive mission. Less idle than refuse truck cycle (~20%).
CBD Truck*	Geometric cycle representative of city heavy vehicle mission. Less idle than refuse truck cycle (~15%).
Measured	Measured on refuse truck in UK. Population density not as heavy as in large city.





Discussion



Initial study indicates significant fuel economy benefit potential from hybrids.

- Hydraulic Hybrid - Best average and most consistent improvement
- Series Hybrid - Largest single cycle fuel economy benefit.
- Parallel Hybrid - Good fuel economy with relatively simple modifications.

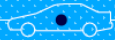
Further Work

- Refine assumptions, inputs, and trade studies
- Investigate further architecture and sizing trade studies.
- Evaluate cost, payback, weight against benefits for each architecture.
- Hardware validation.
- Application of methodology to other vocations (e.g. delivery and/or utility truck).

Advantages of Using EASY5 + Ricardo Libraries

- Fast model construction
- Validated component models
- Easy parameterization
- Flexible model
- Cost effective





Summary



Methodology for evaluating hybrid powertrain performance has been demonstrated.

- Characterize real-world mission using in-vehicle measurements.
- Establish performance requirements.
- High level analysis to provide guidance, support preliminary sizing.
- High fidelity simulation for system integration, refinement.

Simulation is valuable in supporting objective assessment of tradeoffs.

The greatest benefit from hybrid powertrain is obtained when the architecture is matched to the driving mission.

MSC.EASY5 with the Ricardo libraries is well suited for this work.