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Powerpack evaluation for HD hybrid powertrains

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Agenda

- Introduction
- Role of simulation in development
- Pre-transmission powerpack procedures

Introduction

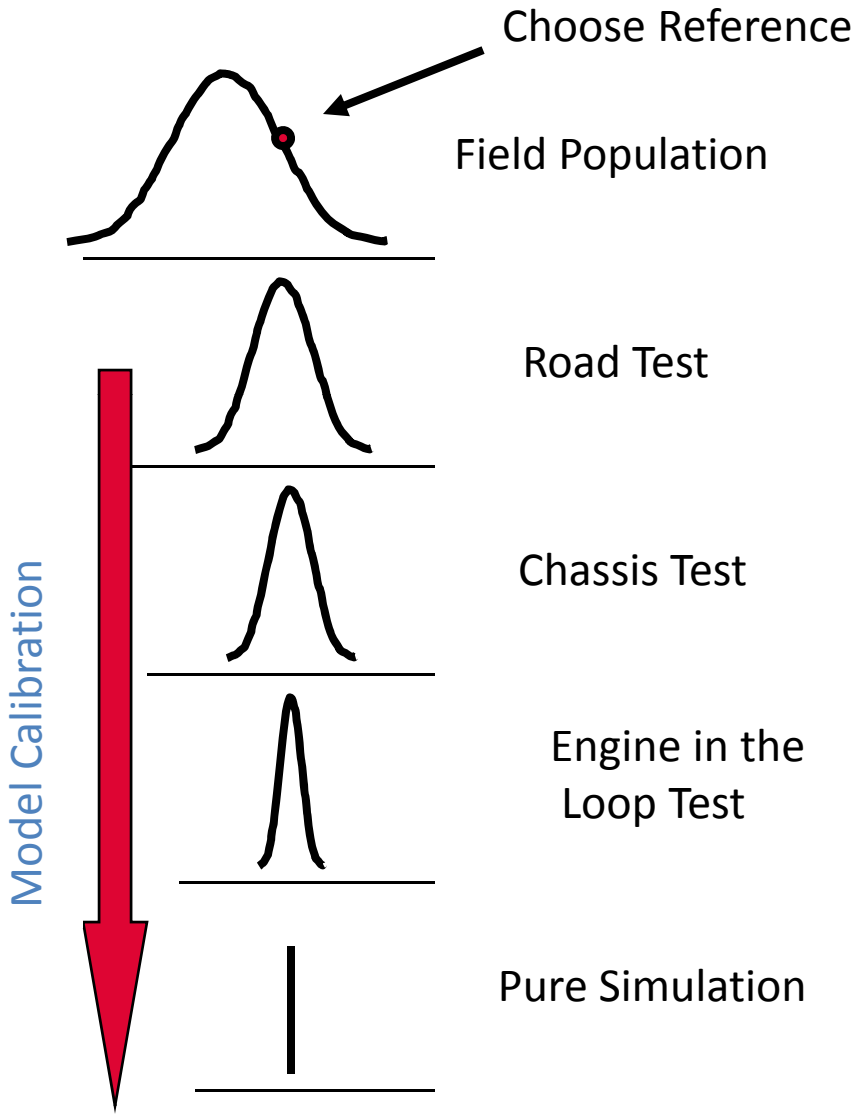
- Objectives of this material:
  - Discuss advantages/challenges for use of simulation in hybrid evaluation
  - Review powerpack concept
  - Review pre-transmission procedures

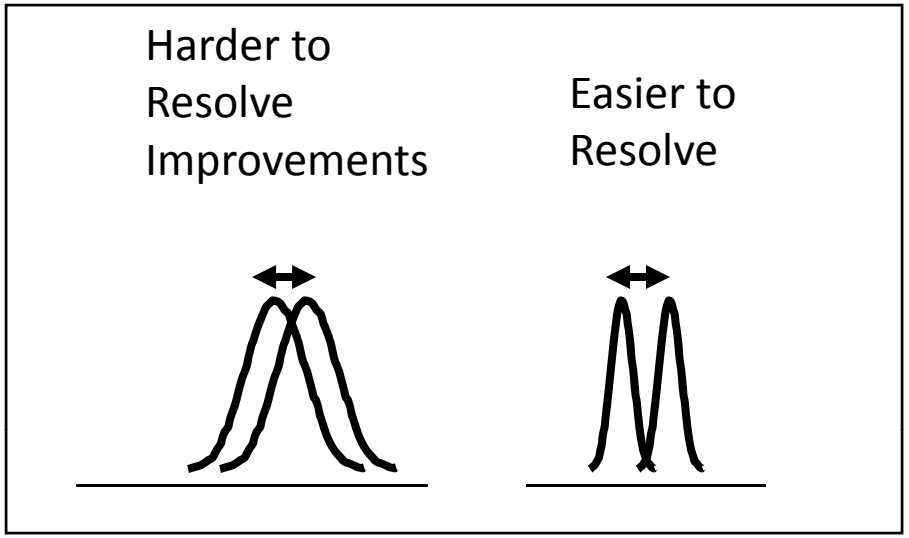
Background

- Cummins is working with industry partners and EPA to help define hybrid evaluation procedures for the new CO2 rule
- Work has included providing hardware for testing at EPA
  - Engine for powertrain evaluation with Eaton hybrid system
  - Prototype hybrid system for pre-transmission powerpack testing
- Current status
  - Hardware installed in test cell
  - Testing to demonstrate procedures beginning

Systems Simulation

Simulation allows for highly repeatable evaluation

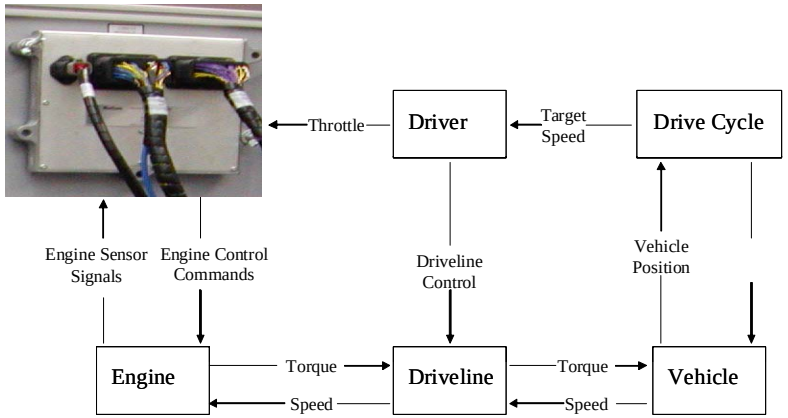


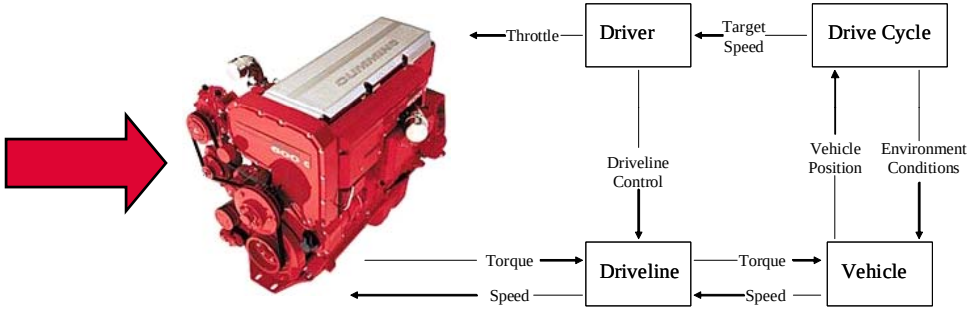


- Simulation highly repeatable
- Accuracy depends on model validation

Analysis Led Design Engine Development

Hardware In the Loop





- Engine Parameter Studies
- Coupled Torque, Flow, Temperature
- Steady State and Transient

- Real Engine and Aftertreatment Controls Interactions
- Real Engine Performance and Emissions
- Drive Cycle Transients

Simulation is an ideal environment for certain work
Simulation is not a low cost solution for all work
Some work is best done in hardware

Use of simulation

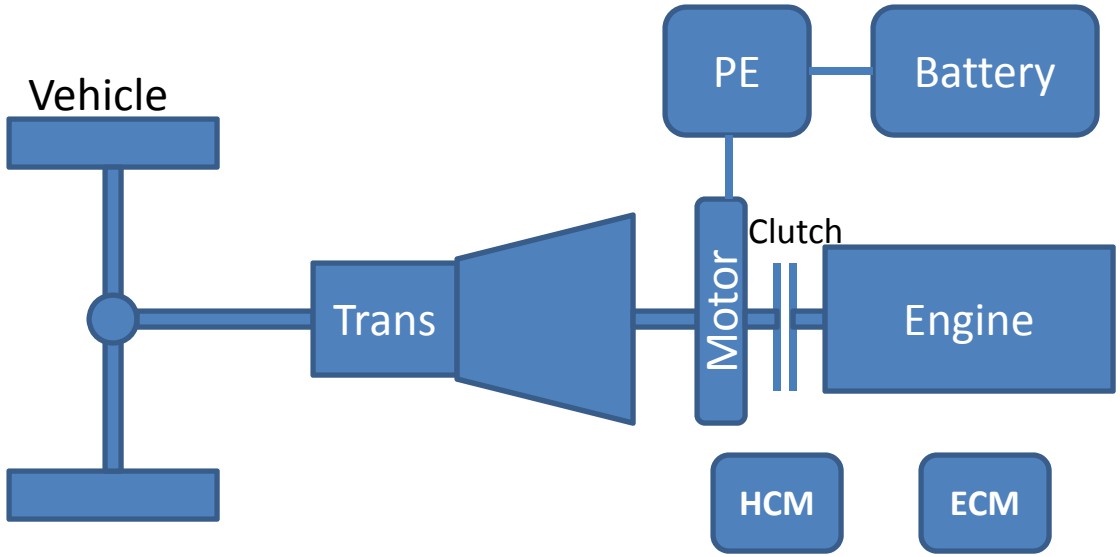
- When should simulation be used?
  - When models are accurate
  - When model development is lower cost than hardware testing
  - When hardware testing would be impractical
- When should simulation be avoided?
  - Hardware test is lower cost
  - Models are not accurate
  - Models are difficult to validate

Hybrid Evaluation Options

Chassis Dyno

Simulated
Road Load

Hardware
Vehicle

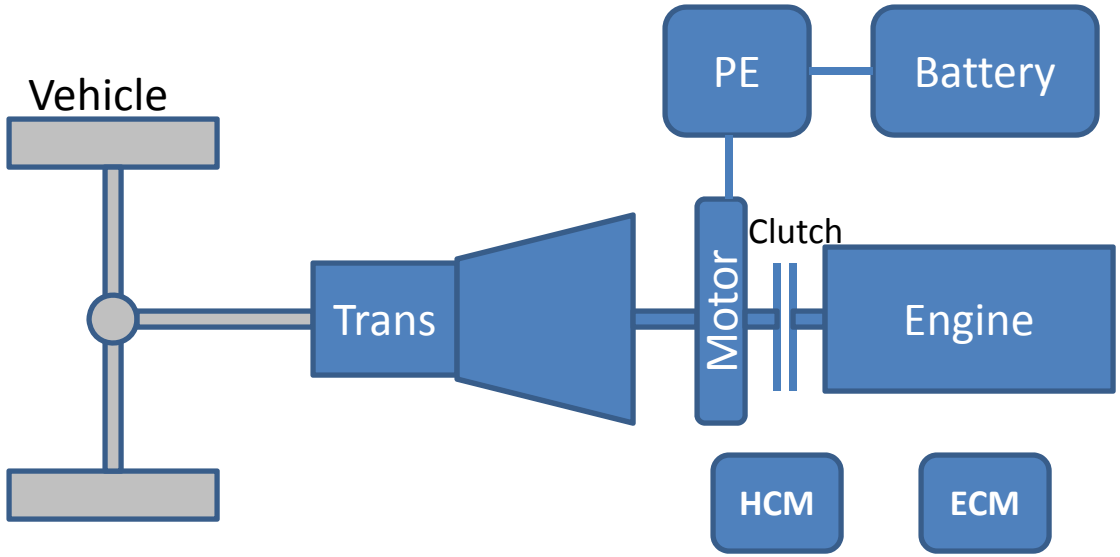


Hybrid Evaluation Options

Post-Transmission Powerpack Simulated Chassis Dyno

<u>Simulated</u>
Road Load
Vehicle

<u>Hardware</u>
Powertrain



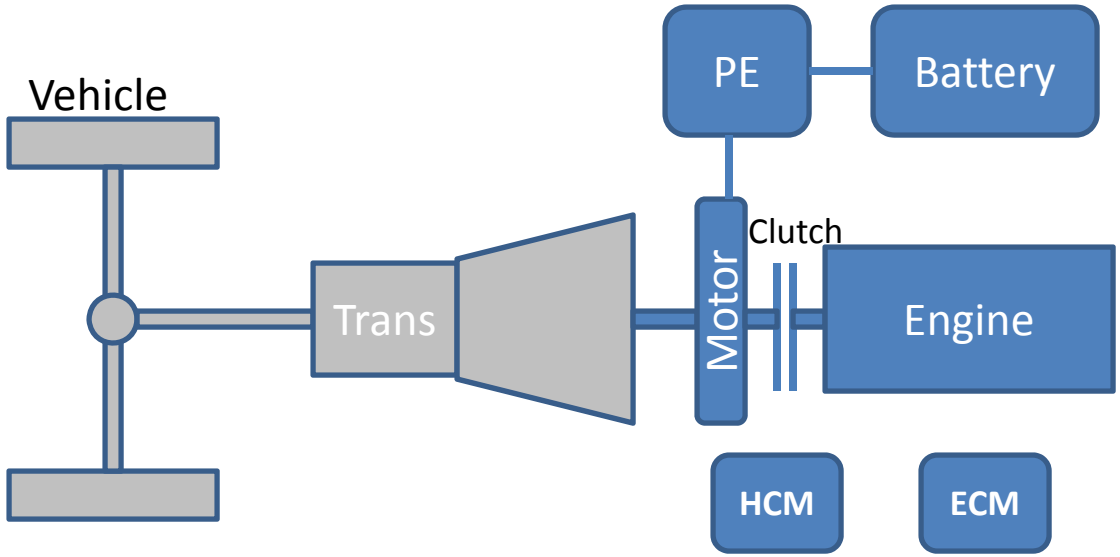
* System could instead be a series, 2 mode, or other hybrid powertrain

Hybrid Evaluation Options

Pre-Transmission Powerpack
Hybrid Engine Dyno

<u>Simulated</u>
Road Load
Vehicle
Transmission

<u>Hardware</u>
Engine
Hybrid components
Controllers

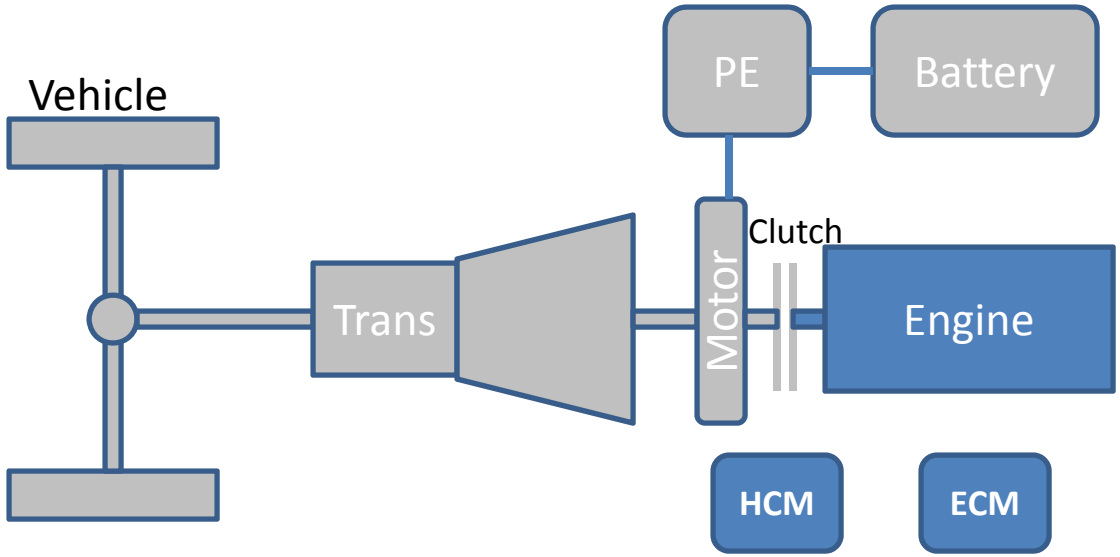


Hybrid Evaluation Options

EIL

<u>Simulated</u>
Road Load
Vehicle
Transmission
Hybrid components

<u>Hardware</u>
Engine
Controllers

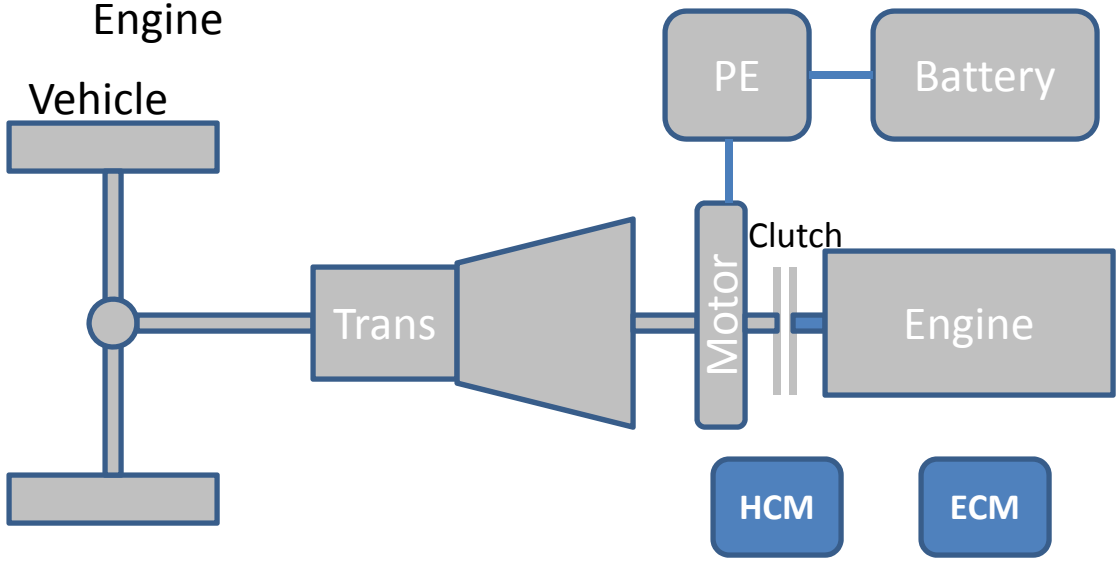


Hybrid Evaluation Options

HILS

<u>Simulated</u>
Road Load
Vehicle
Transmission
Hybrid components
Engine

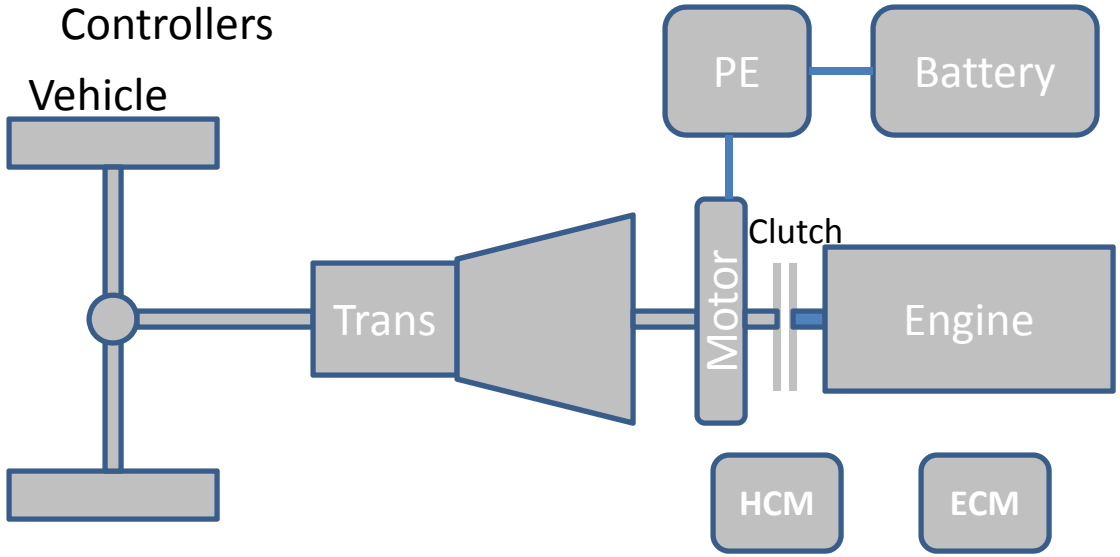
<u>Hardware</u>
Controllers



Hybrid Evaluation Options

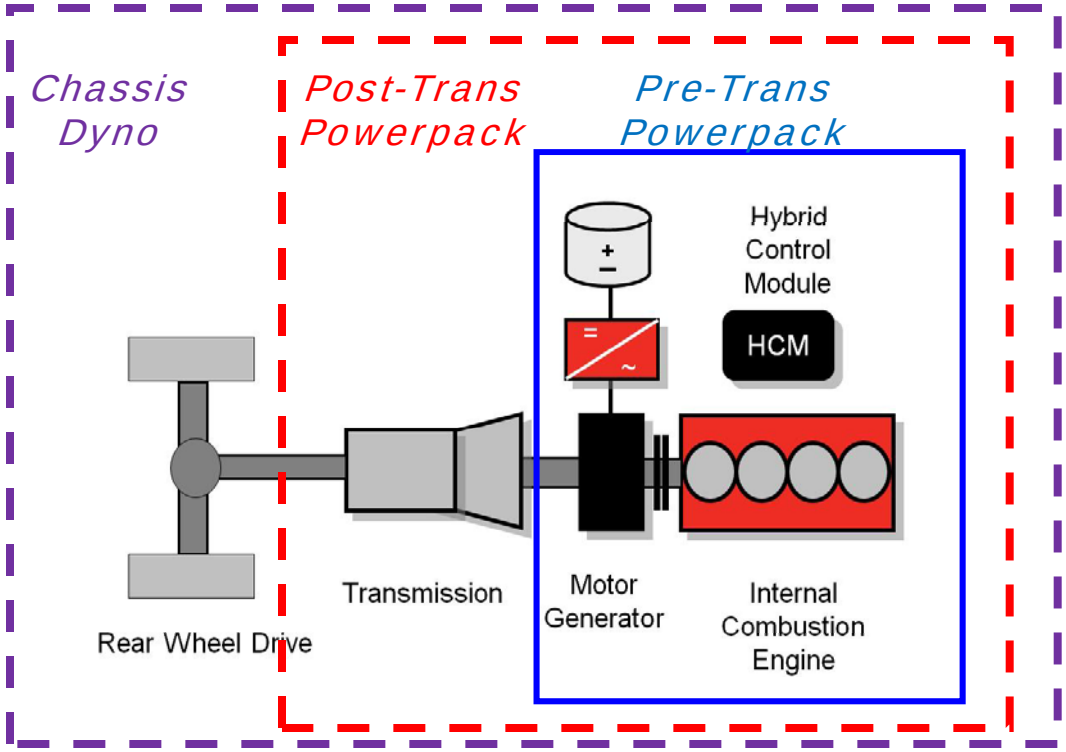
Pure Simulation

<u>Simulated</u>
Road Load
Vehicle
Transmission
Hybrid components
Engine
Controllers



NPRM for CO2: Hybrid Certification Options

- NPRM provides flexibility for first phase of CO2 rule
  - 3 options for evaluation
  - Allows for learning
  - Recognizes diversity of commercial market
- Initial options include hybrid components in hardware



Hybrid Evaluation Should Build on Existing Engine Certification

- Existing transient engine dyno test accurately describes vehicle power requirements for a wide range of vocational applications
- Significant industry experience with engine test procedures and protocols

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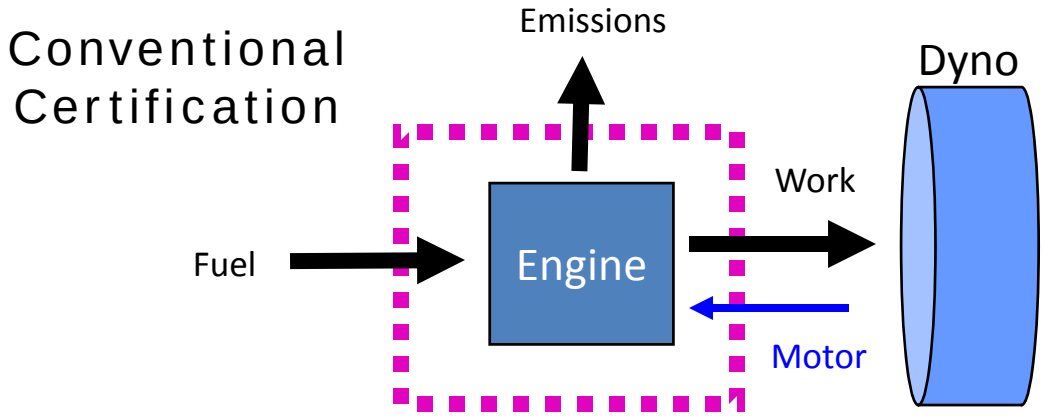
- Use the normalized engine form of the cycle
- Engine torque curve defines actual speed and torque for certification test
- Emissions: g/hp-hr
- Integrate only positive work (motoring work not included)

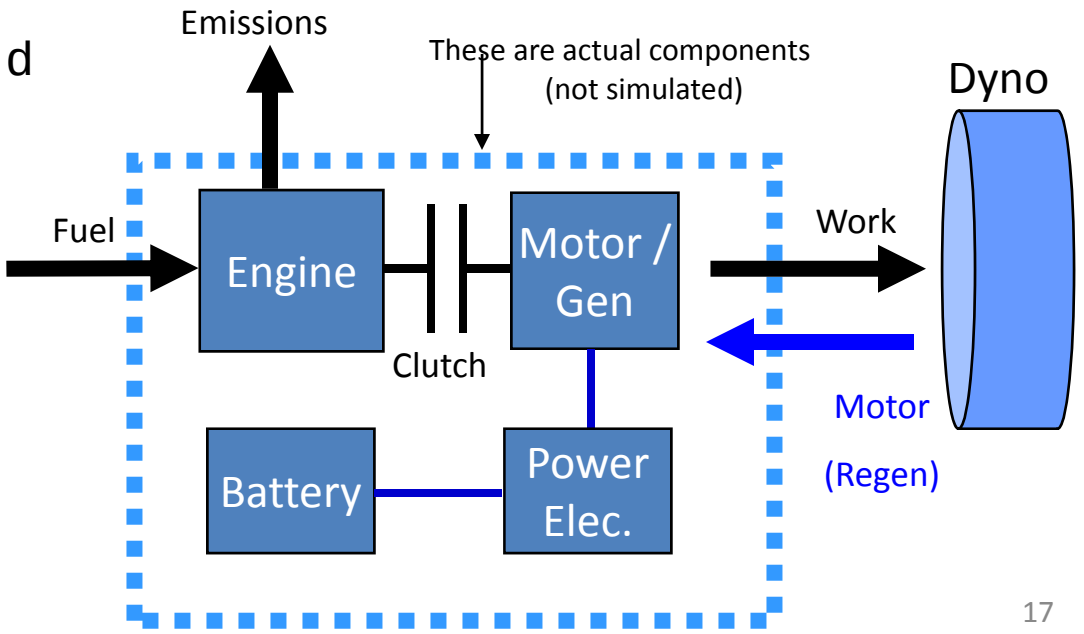


Hybrid Evaluation of Pre-Transmission Hybrids

- Pre-transmission powerpack could utilize existing procedures and protocols with minor modifications
- For many hybrid systems this approach would allow hardware evaluation of engine, motor, battery, etc.
- One certification, many applications
  - Uses same simplifying assumptions as conventional certifications
- Allow comparative performance evaluation with conventional engine

Hybrid Evaluation: Pre-Transmission Hybrid

- Use the normalized engine form of the cycle(s)
- Pre-transmission system torque curve defines actual speed and torque for certification test
- Emissions: g/hp-hr
- Allow capture of energy during "motoring" portions of engine cycle
- Count only positive work (as with conventional engines)



Post-Transmission Power Pack Evaluation

- Pre-transmission powerpack certification not viable for all hybrid architectures
- Post-transmission powerpack certification would work for series and other transmission integrated hybrid systems
- Cycle based on engine test cycle would allow comparative evaluation with conventional and pre-trans hybrid

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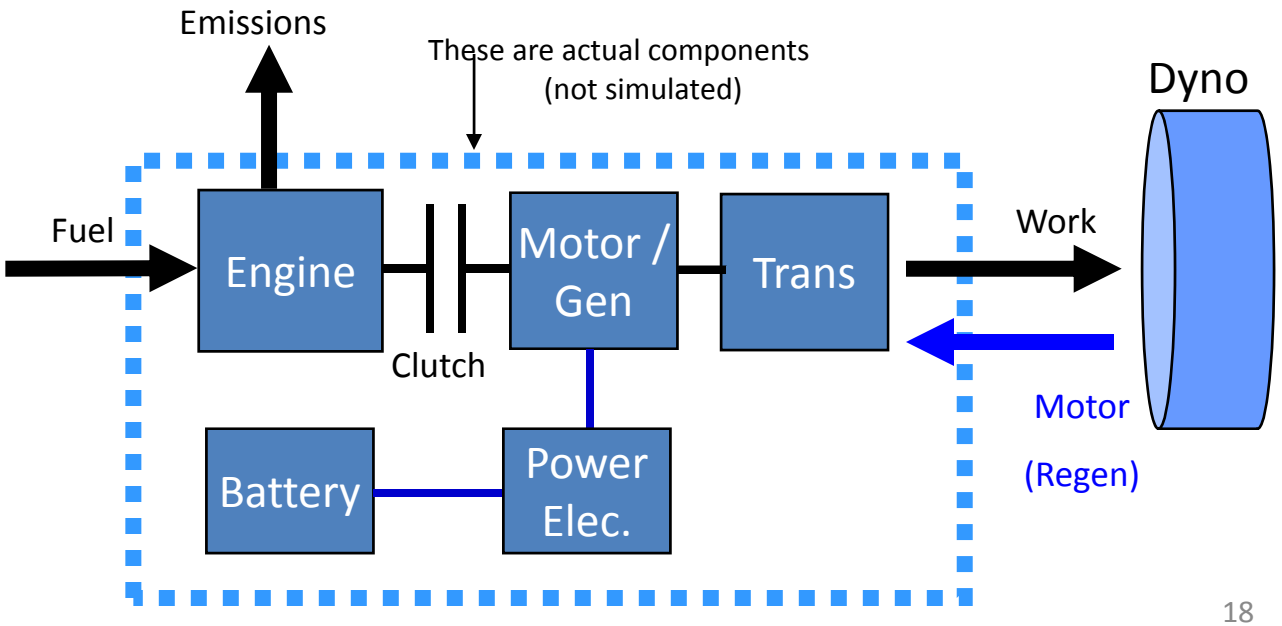
Hybrid Evaluation: Post-Transmission Option

- Use normalized post-transmission test cycle(s)
- Post-transmission system torque curve defines actual speed and torque for certification test
- Emissions: g/hp-hr
- Allow capture of energy during braking portions of cycle
- Count only positive work (as with conventional engines)



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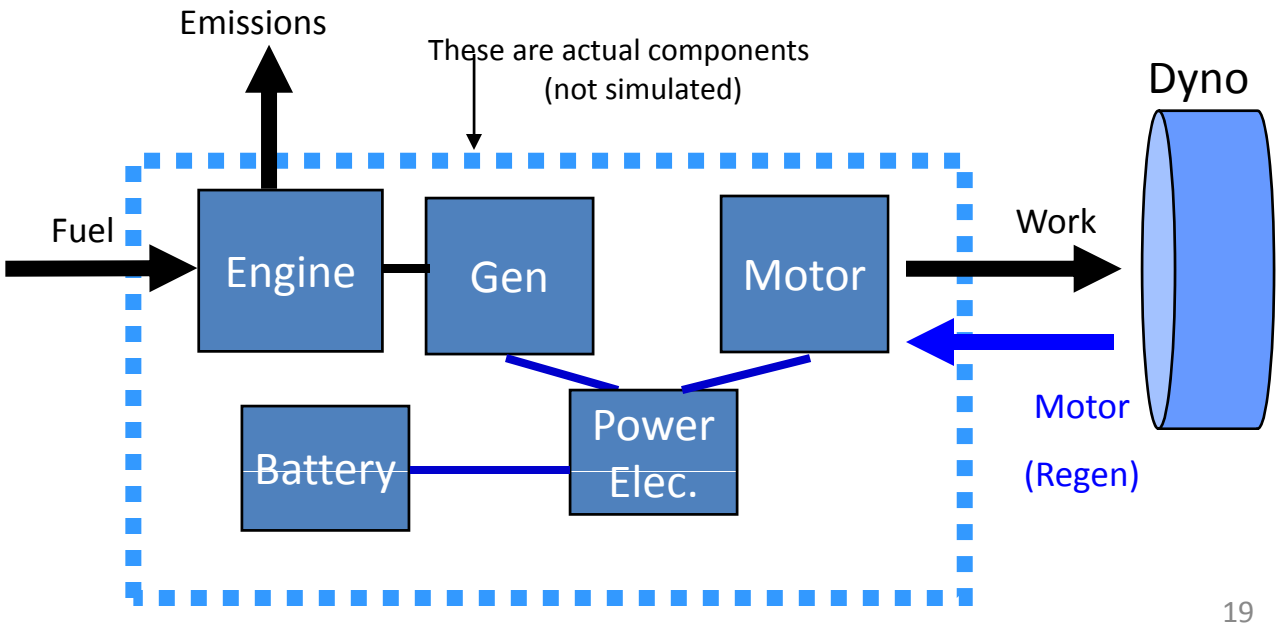

Pre-Transmission Powerpack Procedures: Modifications of existing engine test procedures

- Definition of torque curve
  - Use system transient torque capability to define torque curve
- Energy storage management
  - Follow same procedures as other test methods
  - SAE J2711 describes requirements for energy storage management
- Allow energy capture during motoring portions
  - Define upper limit on regen capture:
    - Motoring torque curve as 40% of positive torque curve per 40 CFR 1065.510
  - Define vehicle cycle and use to calculate available regen energy capture (upper limit).
- Allow zero speed during idle portions
- Count only positive work
  - Same as conventional engine

Summary

- Simulation will play a role in any evaluation method
  - Simulation can reduce cost
  - Challenges for great use of simulation include:
    - How are models validated?
    - How broadly can validated models be applied?
    - Who owns and maintains models?
- In near term, building on existing test procedures simplifies introduction of new hybrid evaluation methods
  - Powerpack procedures can be implemented quickly
- Flexibility is needed for commercial market
  - Wide range of applications and architectures
  - Outside of Europe, vertical integration is less common