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Developing a Standardized Test Procedure for Hybrid Vehicles: The Challenge of the SAE HEV Task Force

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Prepared for the 1994 Automotive Technology Development Contractors' Coordination Meeting, Dearborn, MI, October 24–27, 1994

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DEVELOPING A STANDARDIZED TEST PROCEDURE FOR HYBRID VEHICLES: THE CHALLENGE OF THE SAE HEV TASK FORCE

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ABSTRACT

In 1992, the Society of Automotive Engineers (SAE) established a task force to develop a procedure for measuring electric energy consumption, all-electric range, fuel economy, and exhaust emissions for hybrid vehicles; the procedure will be submitted to regulatory agencies as representing the automotive industry's recommendations. The draft procedure is currently being tested on hybrid vehicles. The University of Maryland's parallel hybrid was tested in September 1994, and the University of California–Davis' parallel hybrid and the University of Illinois' series hybrid will be tested in November 1994 and January 1995, respectively. The procedure is being modified to incorporate any lessons learned, and the task force hopes to recommend the final procedure to the SAE by mid 1995.

BACKGROUND OF THE PROCEDURE

Hybrid vehicles offer potentially better combinations of fuel economy, emissions, range, and performance compared to either electric or conventional vehicles. In 1992, the Society of Automotive Engineers established a task force to develop a procedure for measuring electric energy consumption, all-electric range, fuel economy, and exhaust emissions for hybrid vehicles; the procedure will be submitted to regulatory agencies as representing the automotive industry's recommendations. The procedure is regarded by the industry as a necessary yardstick comparable to the procedures for electric and conventional vehicles. The task force, chaired by Stephen Poulos of General Motors, has 37 members from 17 different organizations (see Table 1).

The draft procedure has been developed to the point where it will benefit from a round of testing on hybrid vehicles. This testing is under way, and the procedure is being modified to incorporate any lessons learned. The task force hopes to recommend the final procedure to the SAE by mid 1995.

DISCUSSION OF THE PROCEDURE

The task force defines a hybrid electric vehicle (HEV) as a road vehicle that can draw propulsion power from both of the following sources of stored energy: (1) a consumable fuel, and (2) an energy storage system charged by an onboard generator or by a detached offboard source.

Table 1
Organizations Represented on Task Force

Organization	Number of Representatives
Argonne National Laboratory	1
Auto Test Labs	1
Chrysler Corporation	1
Ford	10
General Motors Corporation	5
Hitachi	1
Idaho National Engineering Laboratory	1
Northrop	2
National Renewable Energy Laboratory	2
Onan	1
Society of Automotive Engineers	2
Southwest Research Institute	1
Toyota	2
University of California–Davis	1
U.S. Department of Energy	2
U.S. Environmental Protection Agency	3
Other	1

The six criteria below were developed to put hybrid electric vehicles on a level playing field with electric vehicles (EVs), conventional vehicles, and other hybrid vehicles.

(1) The procedure must apply to any type of HEV design and control strategy.
(2) EVs and conventional vehicles tested by the HEV test procedure should yield the same results as if tested by the existing test procedures for these vehicles.
(3) Driving cycles and measurement methods should be consistent with those used in existing test procedures for EVs and conventional vehicles.

(4) Testing should not require defeating or otherwise forcing the vehicle's control system to perform differently from how it would perform in the hands of customers.
(5) The procedure should be as short and simple as possible.
(6) A statistical estimate of annualized fuel economy and exhaust emissions should be included for HEVs capable of offboard charging to reflect variations in the charging habits and distances traveled daily by customers.

The first four criteria were met by incorporating appropriate parts of existing procedures for EVs and conventional vehicles, and by testing the vehicle in all of its driver-selectable modes. Criterion 5 was met by developing a classification scheme for the hybrids according to a vehicle's all-electric range and its ability to maintain state-of-charge (SOC) over sustained driving; the procedure was then tailored for each of the four categories of hybrids (see Figure 1). Table 2 presents an overview of the procedure, and Figure 2 shows the longest version of the procedure.

Table 2
Overview of the SAE Procedure

- Classify the Hybrid Vehicle
  - Battery versus capacitor versus flywheel energy storage
  - Driver-selectable control modes
- Test Vehicle in Automatic Mode
  - Assume vehicle is charge-sustaining and has a commuting electric range
  - Vehicle/battery preparation
  - Energy consumption tests
  - All-electric range tests
  - Based on test results, determine if commuting versus reserve electric range, and charge-sustaining versus charge-depleting
  - Fuel economy/emissions tests
  - Correct for change in state-of-charge
  - Off-cycle ("4th-Bag") high-load test
- Repeat Testing for Any Other Driver-Selectable Modes (*Optional* calculations for estimating fuel economy, emissions, and energy consumption on an annual basis)
  - Alternate automated hybrid modes
  - Forced all-electric mode
  - Forced engine-on mode
  - Each discrete control setting
  - Upper/lower adjustable settings
- Calculate Annualized Results (***Required*** tests to fully characterize a hybrid vehicle in all of its available operating modes)
  - Daily-travel-distance model
  - Charging-habit model
  - Mode-selection model

Procedures for the other three hybrid categories are abbreviated versions of this long one. Criterion 6 was met by using statistics on driving distance and emissions with and without offboard charging. Figure 3 is a graphical summary of this calculation.

TEST PLAN FOR THE PROCEDURE

The initial round of testing is being done at General Motor's Milford Proving Grounds (Michigan) using hybrid vehicles built by students and faculty at the University of Maryland, University of California–Davis, and University of Illinois (see Figure 4). These vehicles were chosen because of their varied designs, demonstrated reliability, and outstanding performance in the 1994 Hybrid Electric Vehicle Challenge. The testing is being done by a team from General Motors, the Idaho National Engineering Laboratory, and the National Renewable Energy Laboratory.

The University of Maryland's parallel hybrid was tested during September 26–30, 1994. Eight conclusions are summarized below based on the first round of testing.

(1) The SOC compensation technique yielded expected trends in emissions and fuel economy.
(2) More data will be needed to confirm linearity, accuracy, and repeatability of SOC plots.
(3) The largest source of error in amp-hour integration apparently is due to battery inefficiency at high charge rates and high SOCs.
(4) The control strategy used by the University of Maryland's HEV did not work well starting from 100% SOC.
(5) A standard sign convention is needed for current in and current out of the battery.
(6) Vehicles with small fuel tanks may need to be refilled during the test procedure.
(7) An explicit dynamometer warm-up procedure is needed.
(8) Additional time needs to be scheduled before the testing begins to resolve unexpected instrumentation and vehicle problems, as well as to practice driving.

The University of California–Davis' parallel hybrid will be tested during November 14–18, 1994, and the University of Illinois' series hybrid will be tested during January 24–28, 1995.

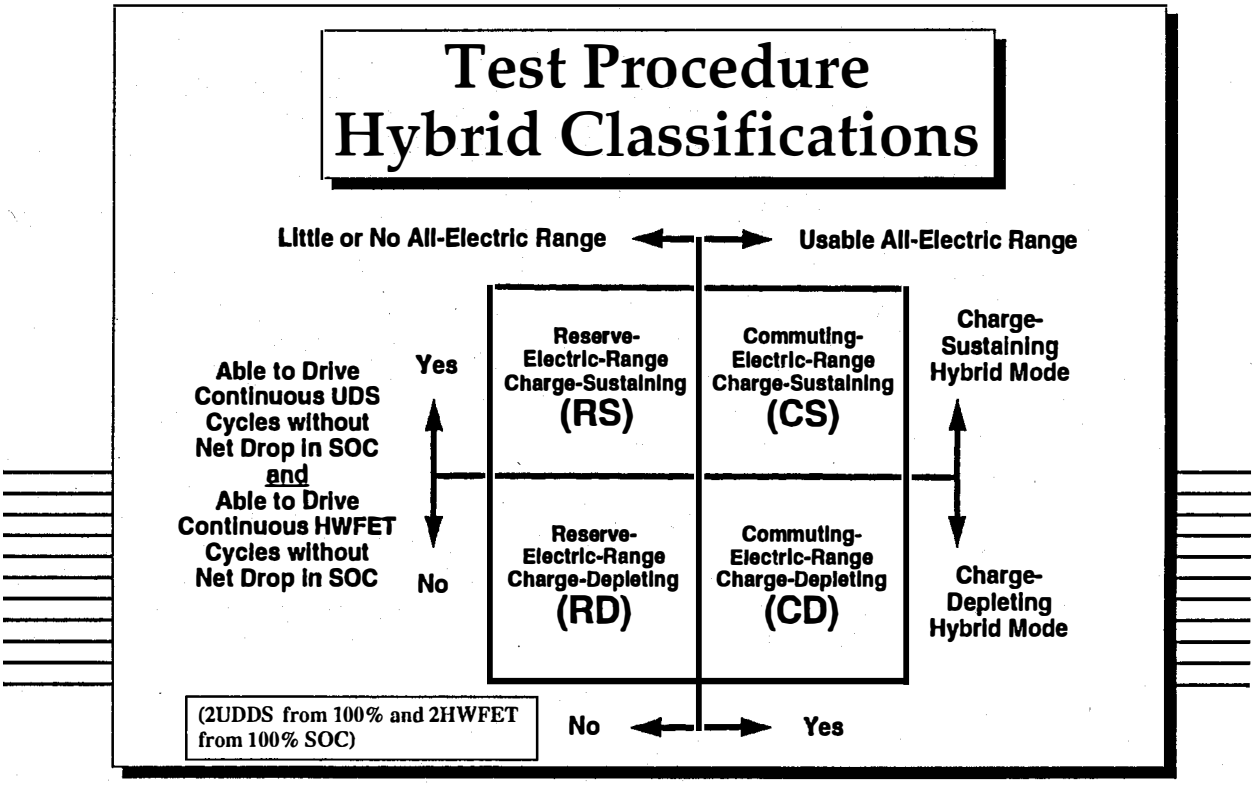

Figure 1: Four categories of hybrid vehicles

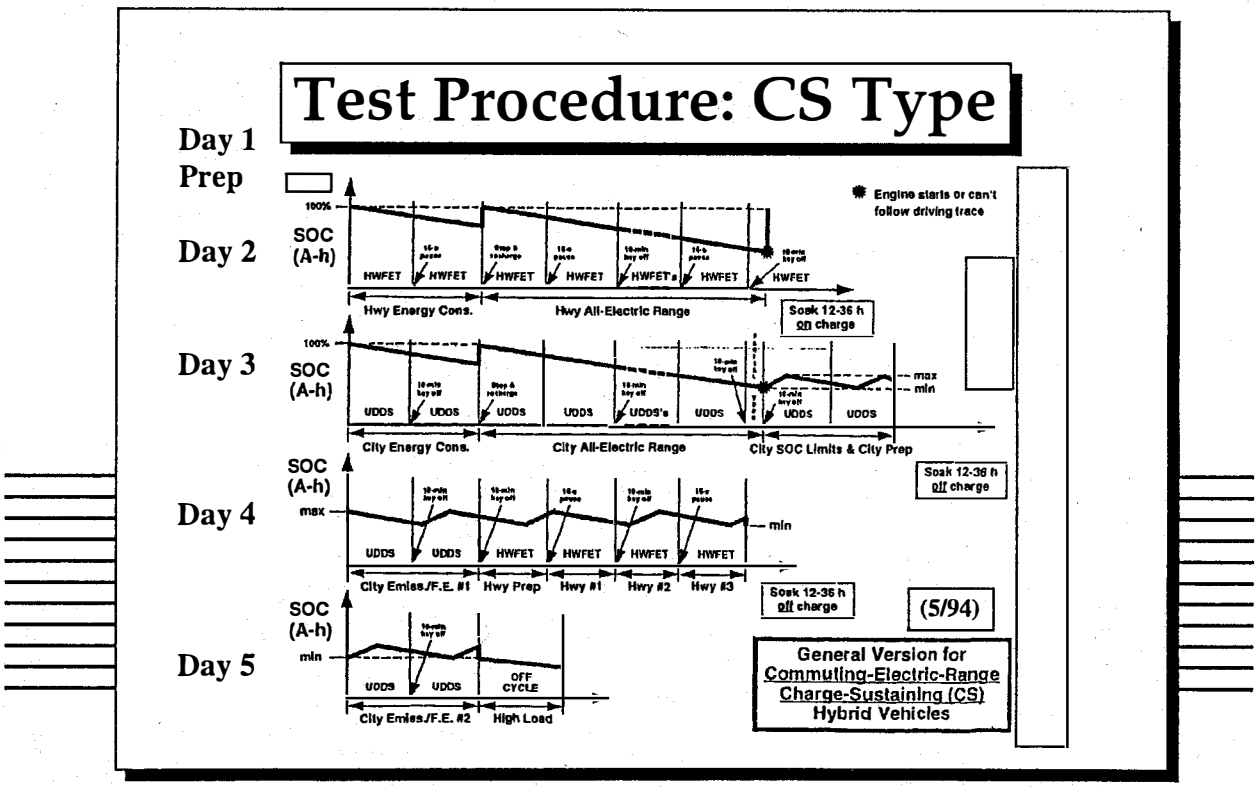

Figure 2: The longest version of the test procedure

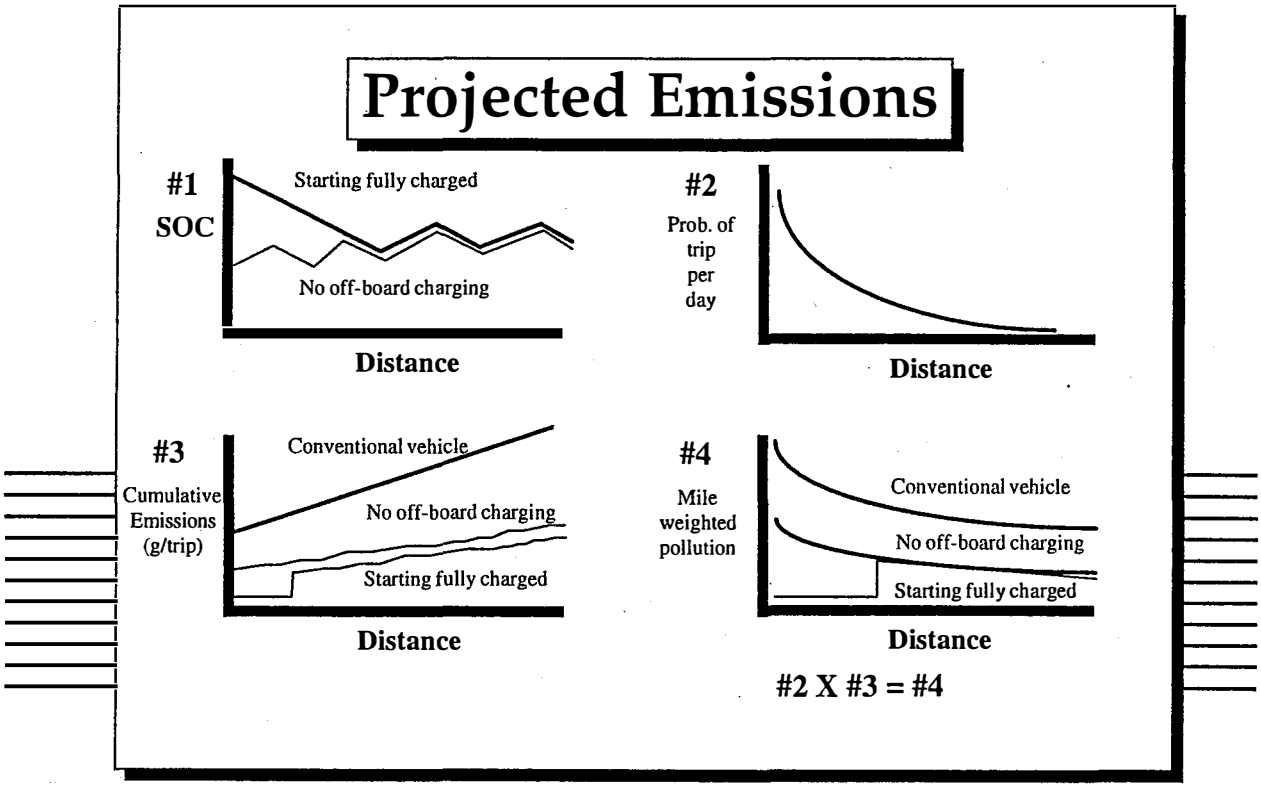

Figure 3: Plots of driving distance and emissions with and without offboard charging

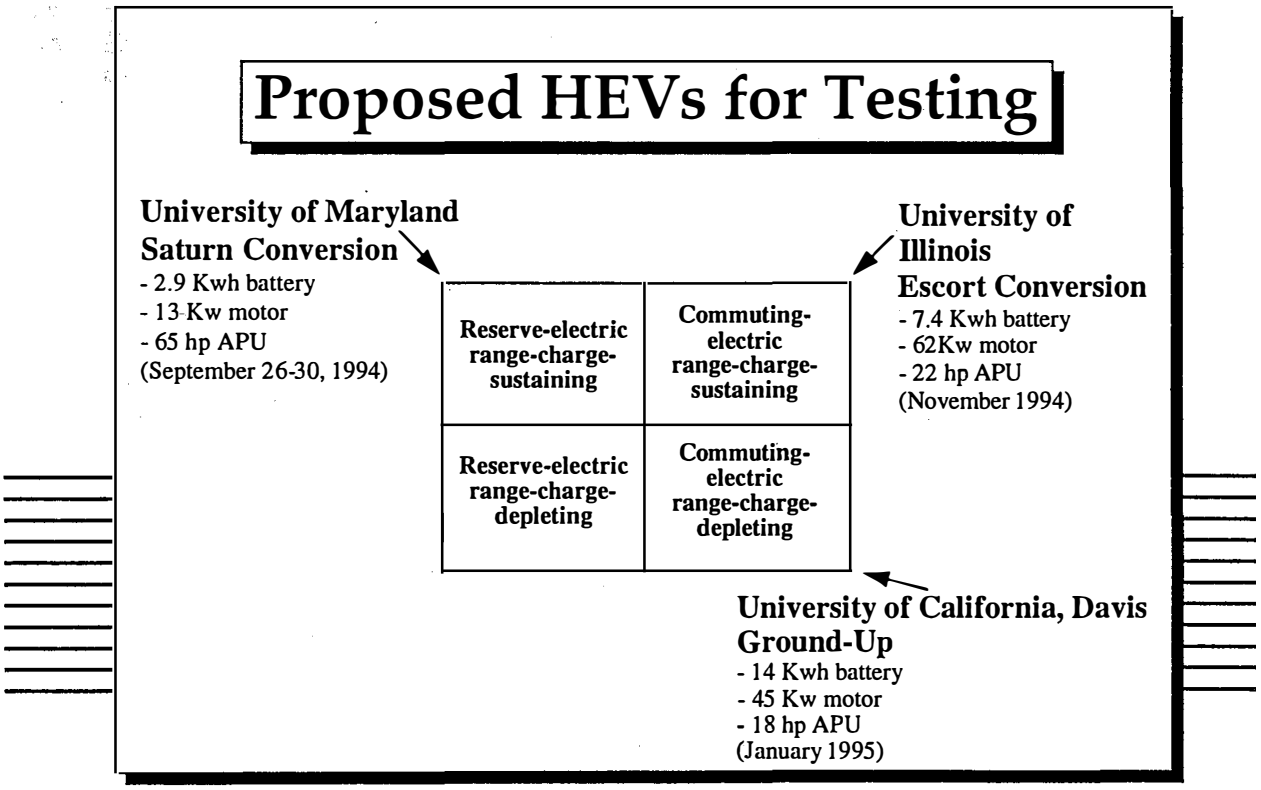

Figure 4: Summary of three hybrid electric vehicles to be tested