

Linking ADAMS and ADVISOR for Advanced Vehicle Evaluation

by
Keith Wipke
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ABSTRACT:

ADVISOR is an advanced vehicle simulator developed by the National Renewable Energy Laboratory, and is capable of evaluating fuel economy, emissions, and basic performance on advanced vehicle concepts. MDI and NREL have worked together to link the dynamic analysis tool ADAMS/Car to ADVISOR to allow a more complete and accurate examination of future vehicle performance. Examples of this integration will be performed with the benefits and likely applications discussed. Future improvements and modifications to the existing linkages will also be discussed. If our customers allow it, we will also discuss application of this suite of tools to a specific vehicle product.



2000 International ADAMS Users Conference

Linking ADAMS/Car and ADVISOR for Advanced Vehicle Evaluation

Keith Wipke

Senior Engineer, Vehicle Systems Analysis Team,
National Renewable Energy Laboratory

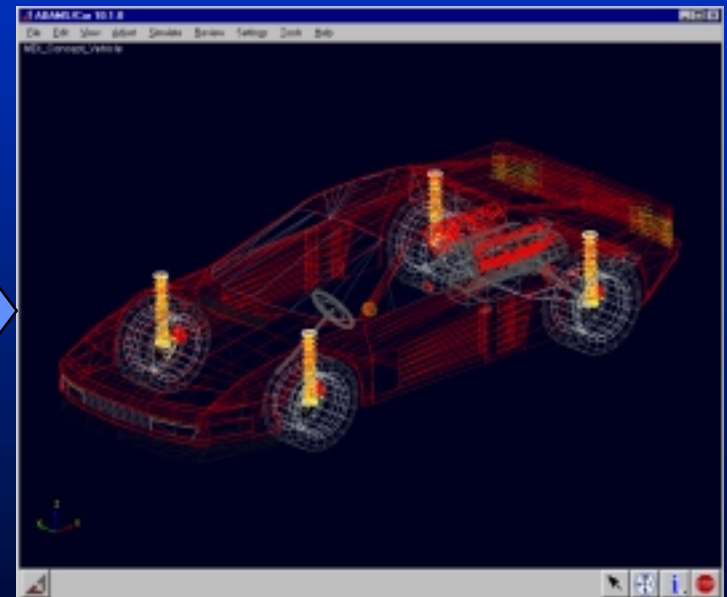
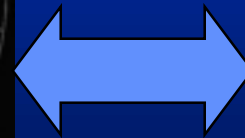


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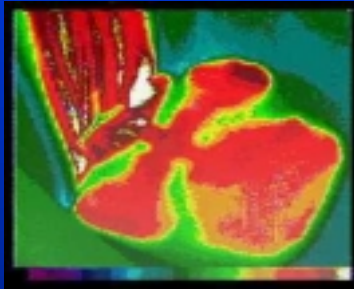


Presentation Outline

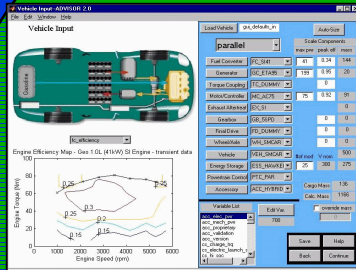
- Background and Demonstration of ADVISOR 2.2
- Objectives of linking ADVISOR and ADAMS/Car
- Details of two approaches to making linkage



Light-Duty Hybrid Electric Vehicle Program



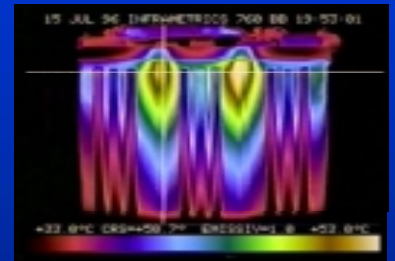
Vehicle Climate Control



Vehicle Systems Analysis



Digital Functional Vehicle



Battery Thermal Management

Big 3 Partnership
(55 mpg, mid-size vehicle)



Chrysler



Ford



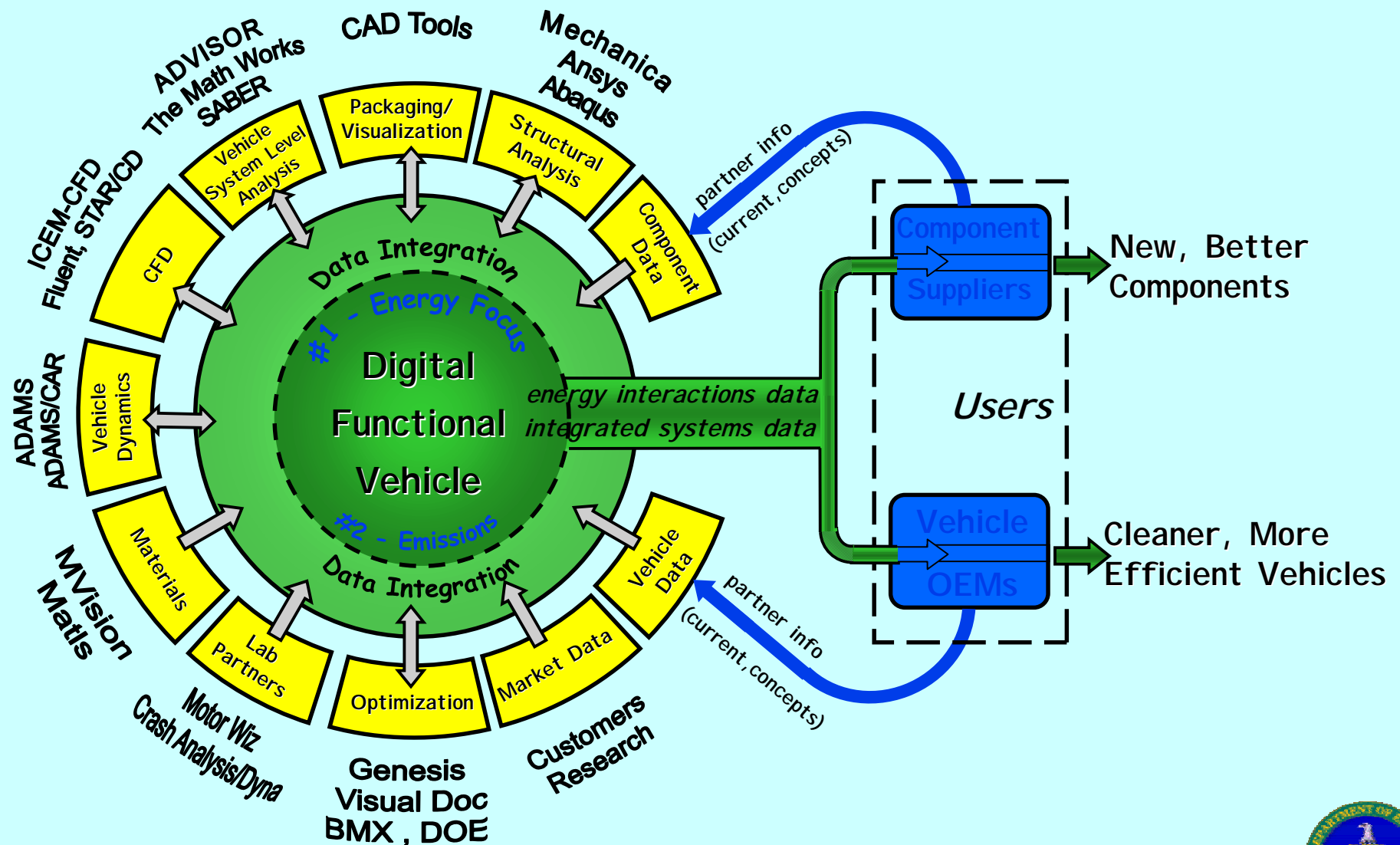
GM



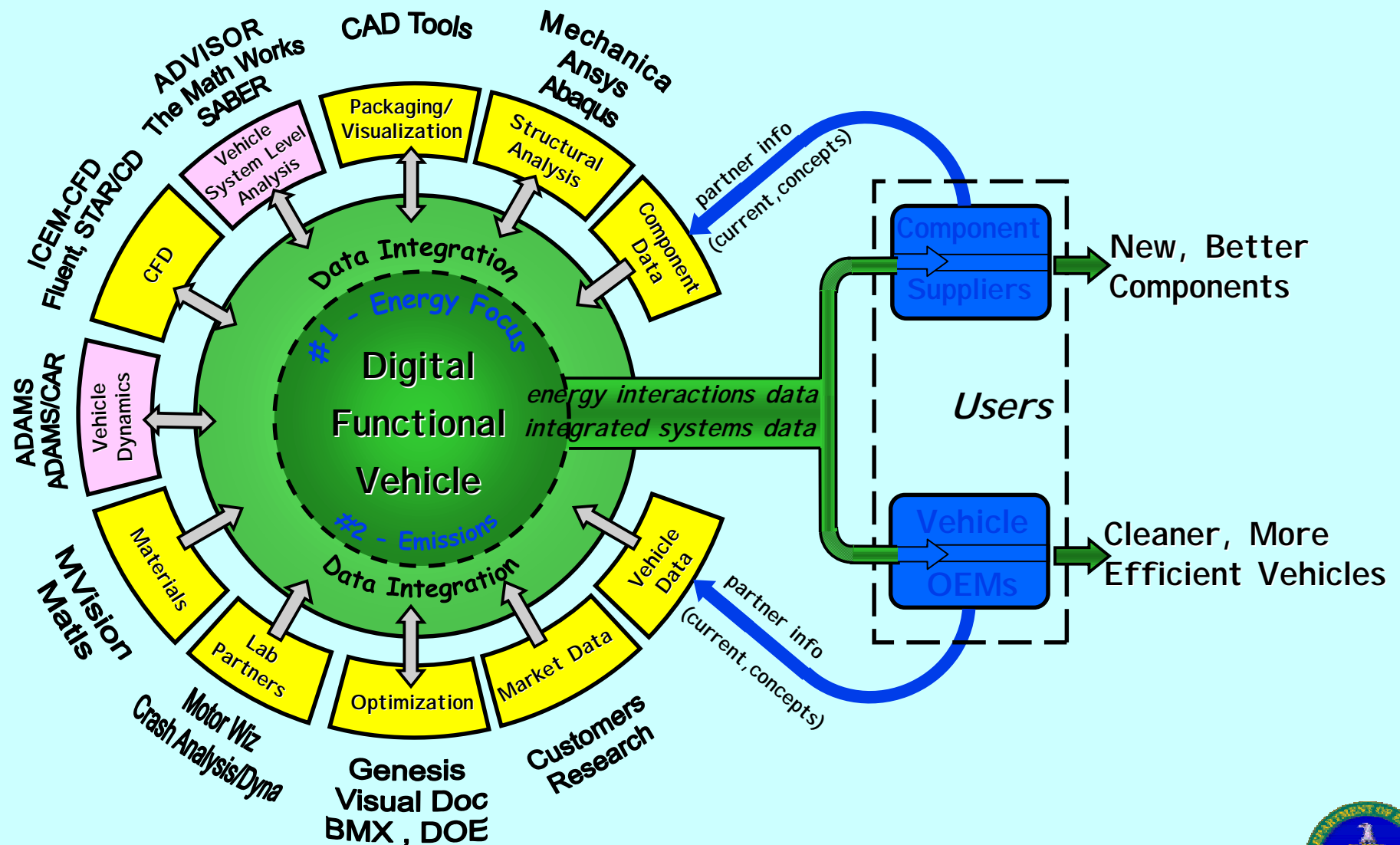
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Digital Functional Vehicle Wheel

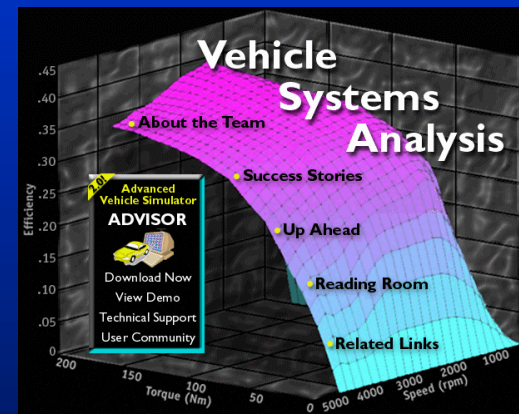


Digital Functional Vehicle Wheel: Linking Systems Level Analysis with Vehicle Dynamics



Background on ADVISOR

- ADVISOR = ADvanced Vehicle Simulator
 - simulates conventional, electric, or hybrid vehicles (series, parallel, or fuel cell)
- ADVISOR was created in 1994 to support DOE Hybrid Program at NREL
- Released on vehicle systems analysis web site in September, 1998
- Programmed in MATLAB/Simulink
- Downloaded by over 1700 people around world
- Users help provide component data and validation

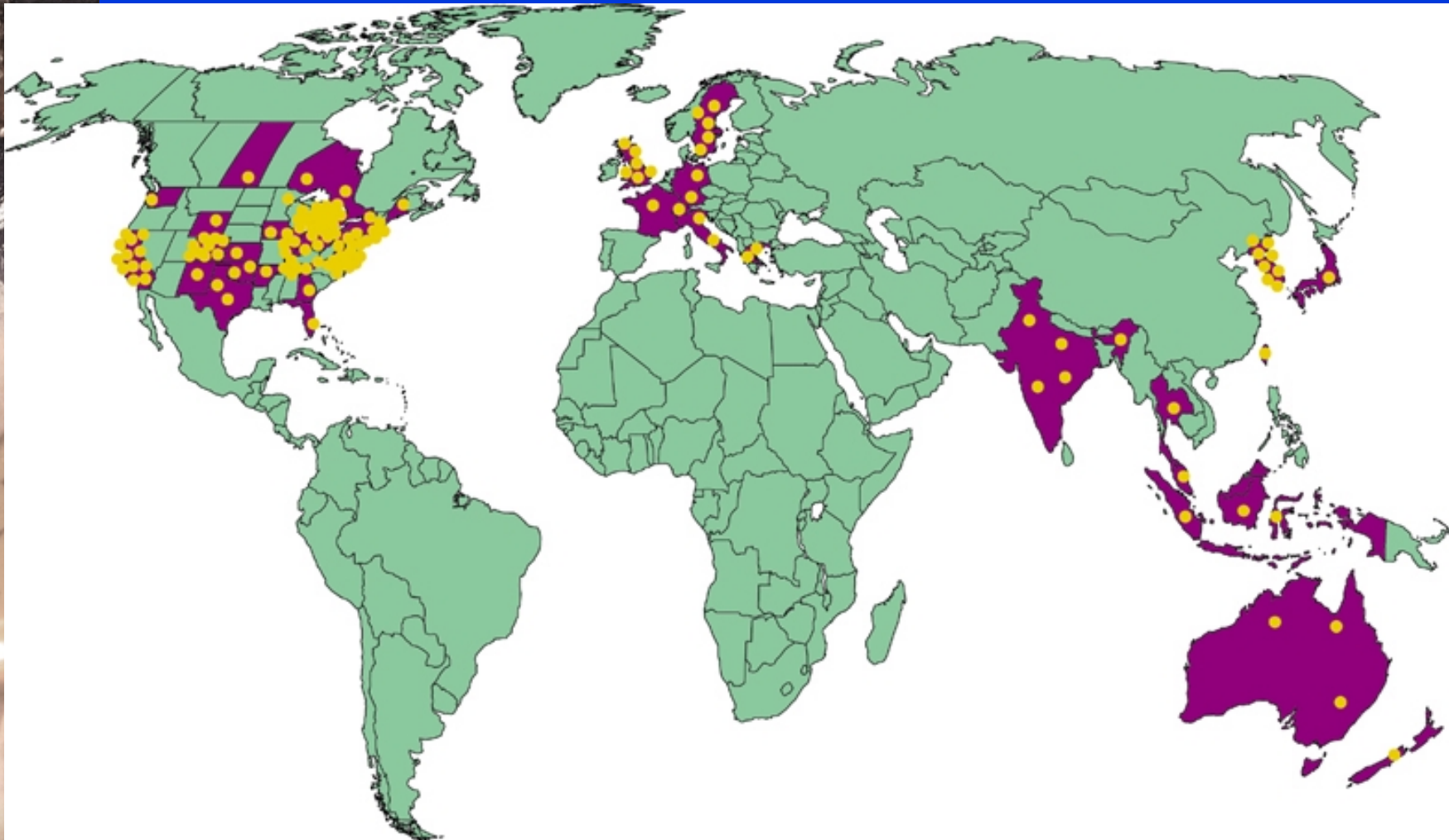


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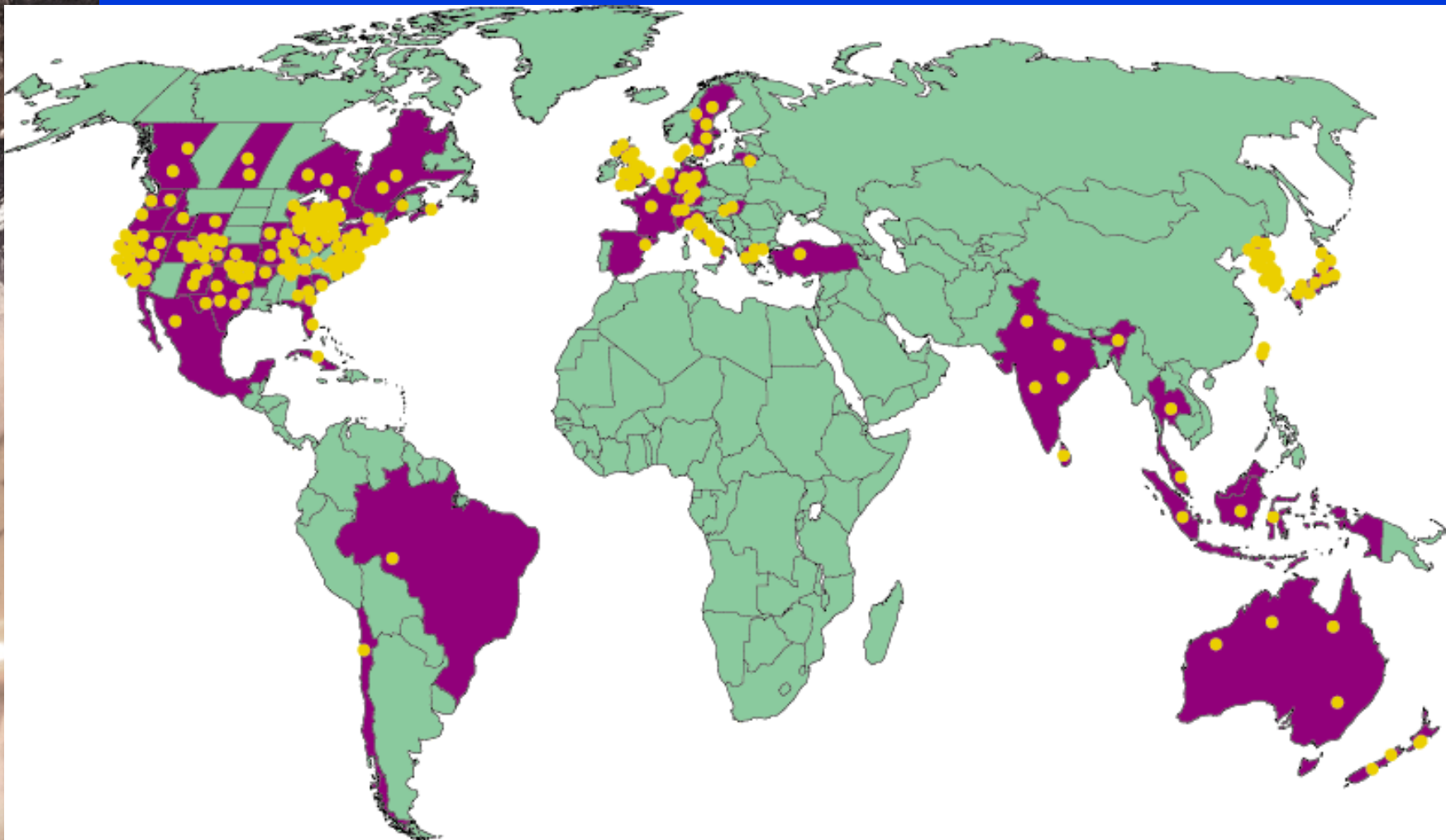
ADVISOR Being Used Globally

November 1998: ~130 users



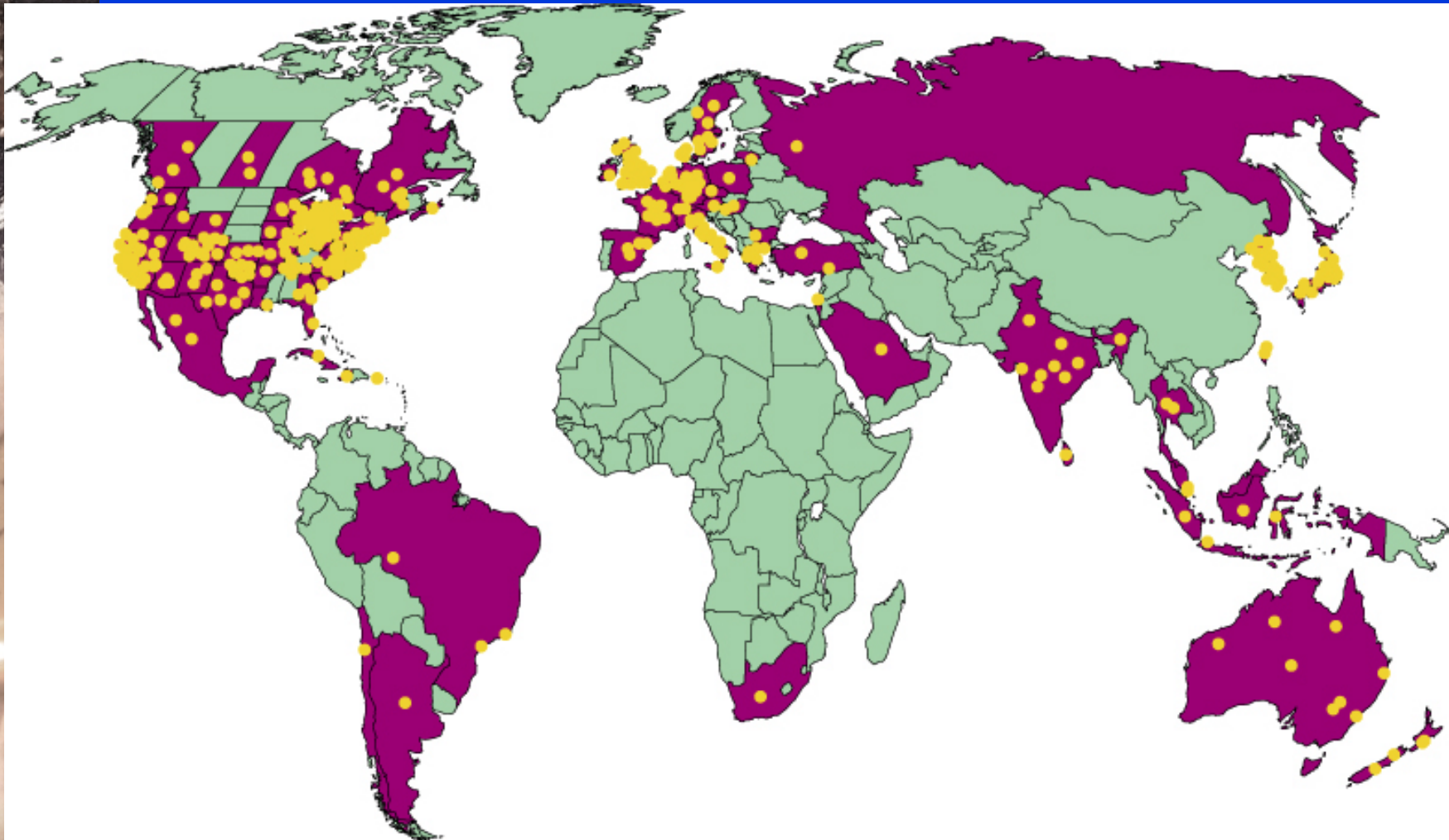
ADVISOR Being Used Globally

January 1999: ~330 users



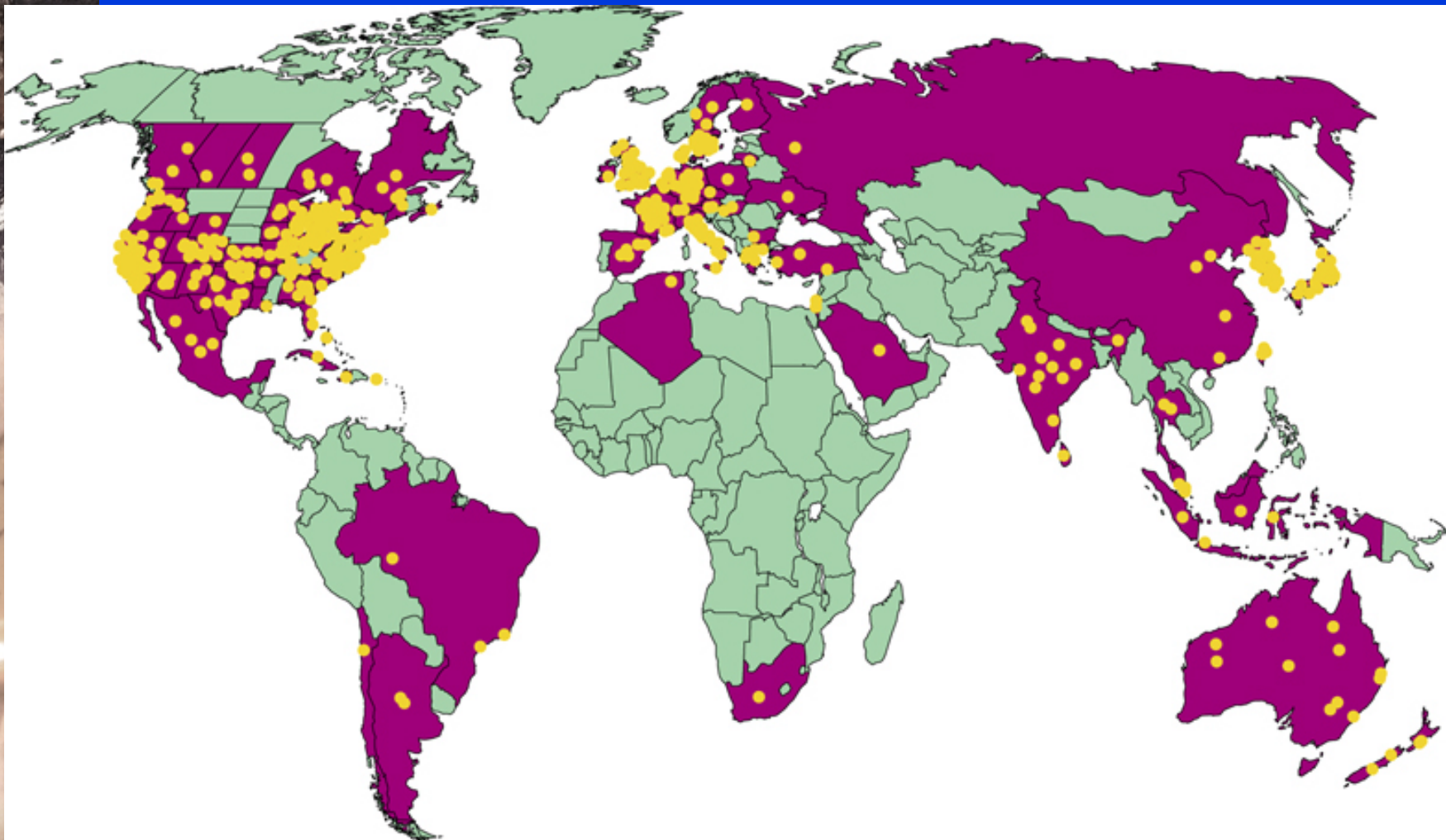
ADVISOR Being Used Globally

March 1999: ~500 users



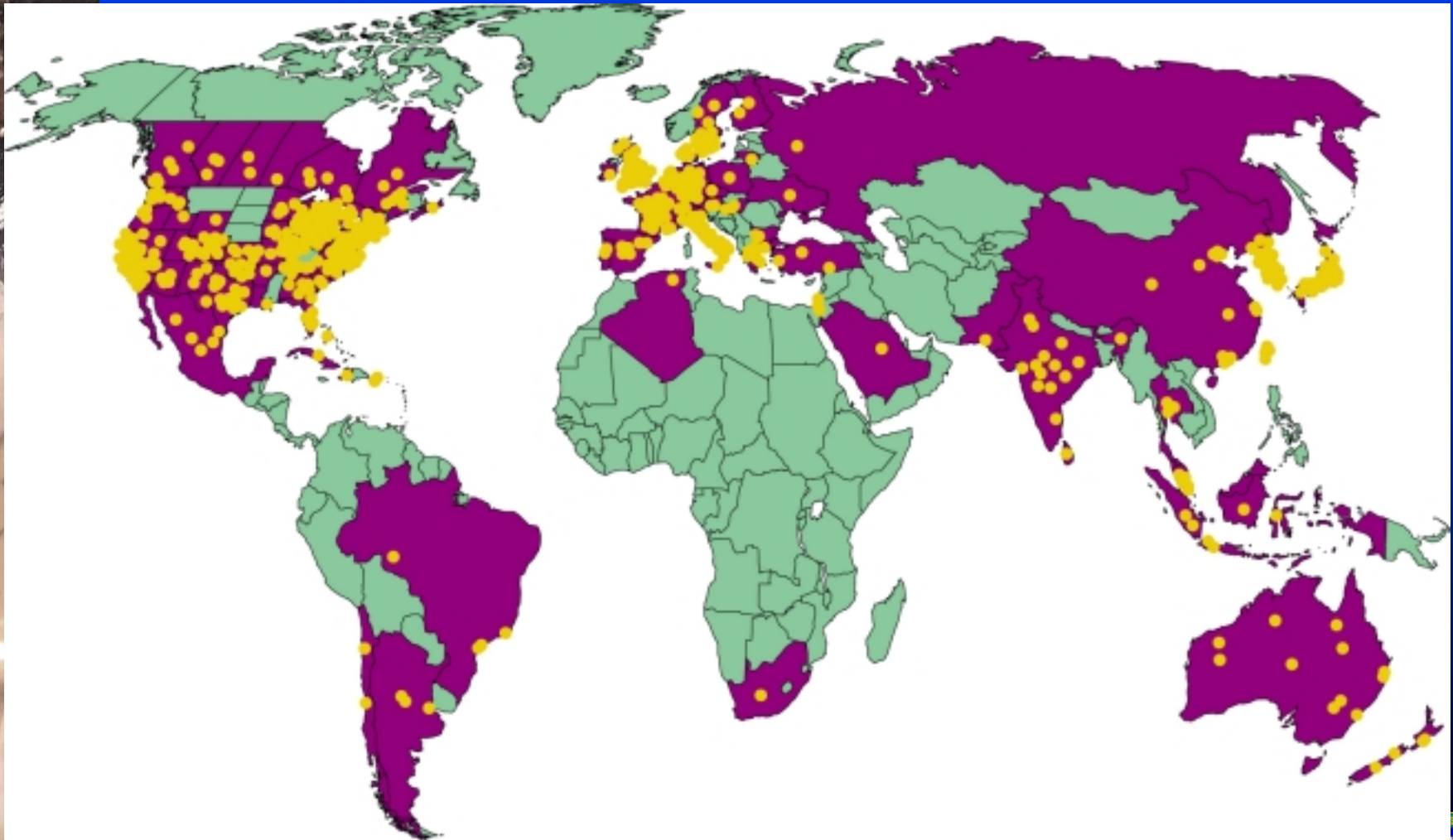
ADVISOR Being Used Globally

August 1999: ~800 users

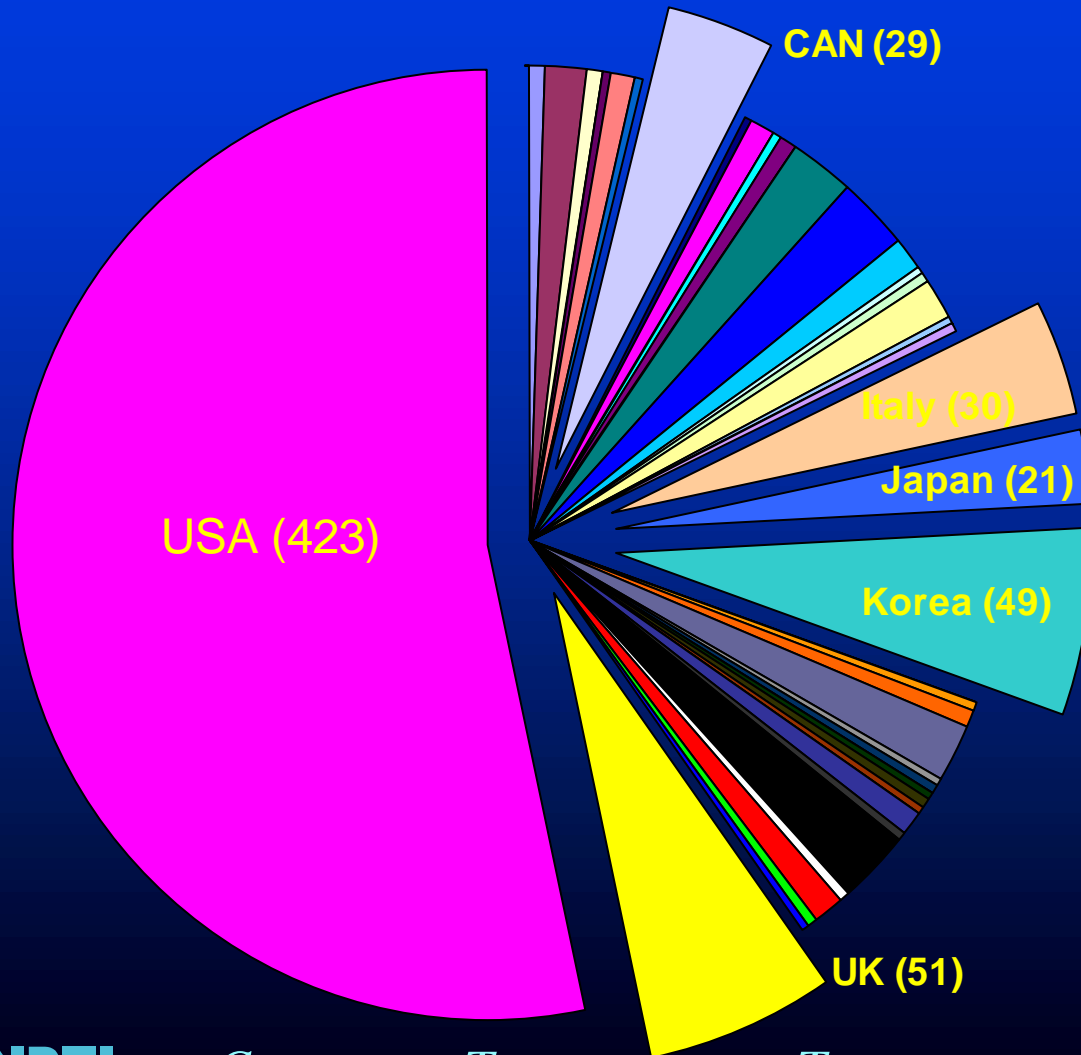


ADVISOR Being Used Globally

June 2000: ~1700 users



ADVISOR Users by Country (as of 8/5/99)



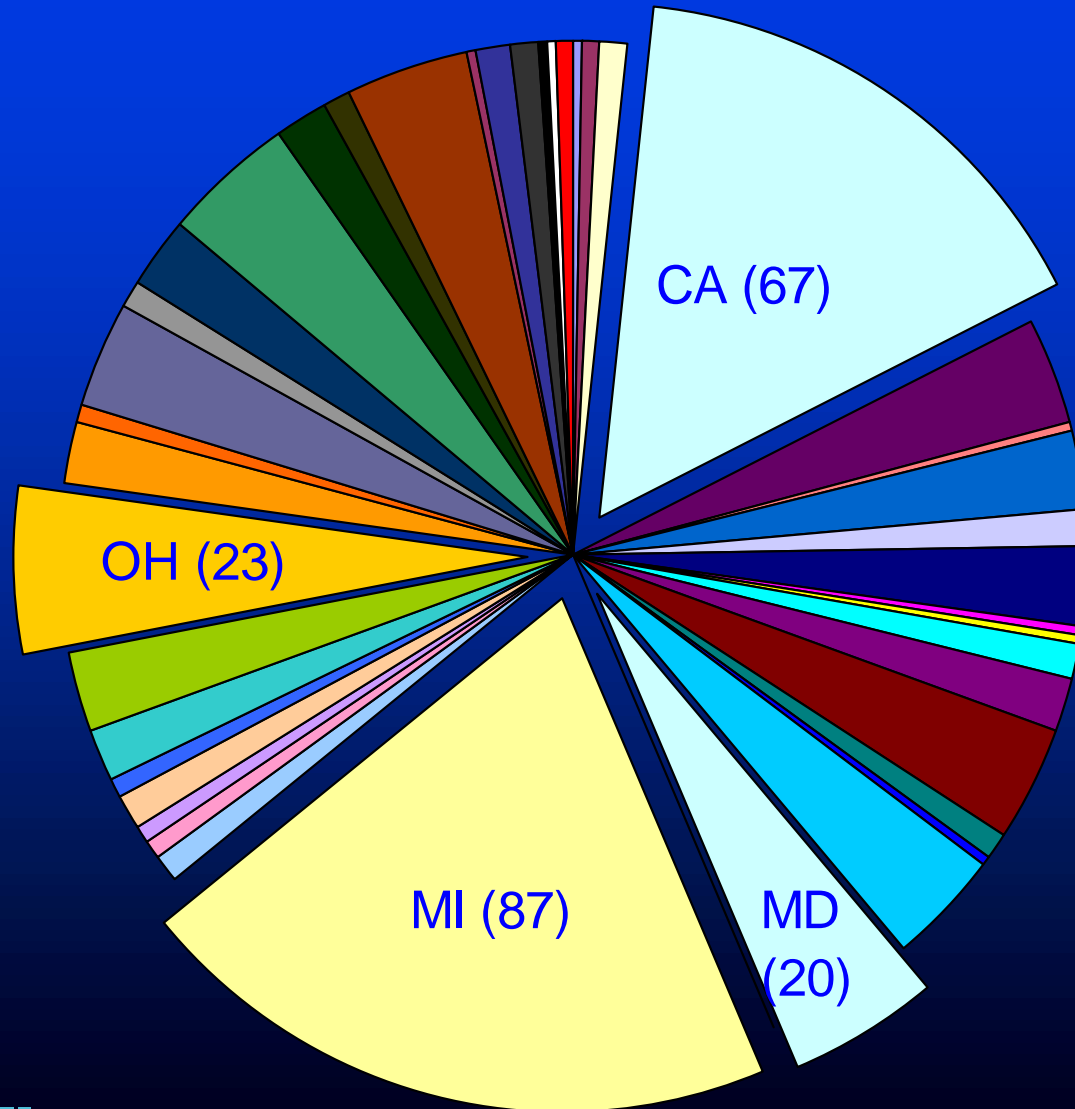
- Argentina
- Australia
- Austria
- (Bahamas)
- Belgium
- Brazil
- Bulgaria
- Canada
- Chile
- China
- Cyprus
- Czech Republic
- Denmark
- Finland
- France
- Germany
- Greece
- Haiti
- Hungary
- India
- Indonesia
- Ireland
- Israel
- Italy
- Japan
- Korea
- Lithuania
- Luxembourg
- Malaysia
- Mexico
- Netherlands
- New Zealand
- Poland
- Portugal
- Russia
- Saudi Arabia
- Singapore
- South Africa
- Spain
- Sri Lanka
- Sweden
- Switzerland
- Taiwan
- Thailand
- Turkey
- United Kingdom
- United States of America



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ADVISOR Users by State (as of 8/5/99)



- Alabama
- Arkansas
- Arizona
- California
- Colorado
- Connecticut
- District of Columbia
- Florida
- Georgia
- Hawaii
- Iowa
- Idaho
- Illinois
- Indiana
- Kansas
- Louisiana
- Massachusetts
- Maryland
- Maine
- Michigan
- Minnesota
- Missouri
- North Carolina
- New Jersey
- New Mexico
- Nevada
- New York
- Ohio
- Oklahoma
- Oregon
- Pennsylvania
- South Carolina
- Tennessee
- Texas
- (Unknown)
- Utah
- Virginia
- Vermont
- Washington
- Wisconsin
- West Virginia
- Wyoming
- (Puerto Rico)



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Significant Usage by Industry and Others

Non-industry users (6 or more)		# of Users	
	Ohio State University		25
	University of Maryland		19
	University of Michigan		17
	Texas Tech University		15
	University of California, Davis		13
	Cornell University		13
	George Washington University		13
	Georgia Institute of Technology		13
	University of Bath (UK)		7
	Pennsylvania State University		6
	Seoul National University (Korea)		6
	West Virginia University		6
	Argonne National Laboratory		5
	NREL		5
	San Diego State University		5
	Texas A&M University		6
	University of Tennessee		6
	Subtotal		147
Industry users (5 or more)		# of Users	
	Other industry users		# of Users
Ford Motor Company	Club Car, Inc.	14	1
DaimlerChrysler	Cummins Engine Co.	13	3
General Motors	Epyx Corporation	13	2
Delphi	Mitsubishi Motors Corp. (Japan)	9	4
Fiat Auto R&D (Italy & US)	New Generation Motors	9	2
Volvo (Sweden)	Nissan (Japan)	9	4
Visteon Automotive Systems	Ricardo	9	2
Parametric Technology Corporation	Rover Group Ltd. (UK)	8	3
AlliedSignal	Siemens AG (Germany/France)	8	3
AVL Powertrain	Technologies M4 Inc. (Canada)	7	4
Honda R&D (USA & Japan)	TNO Automotive (Netherlands)	6	4
Renault (France)	Toyota Motor Corp. (Japan)	6	1
Denso (Japan)	Volkswagen AG (Germany)	6	1
Hino Motors Ltd. (Japan)	Subtotal	6	38
Hyundai Motor Co. (Korea)			

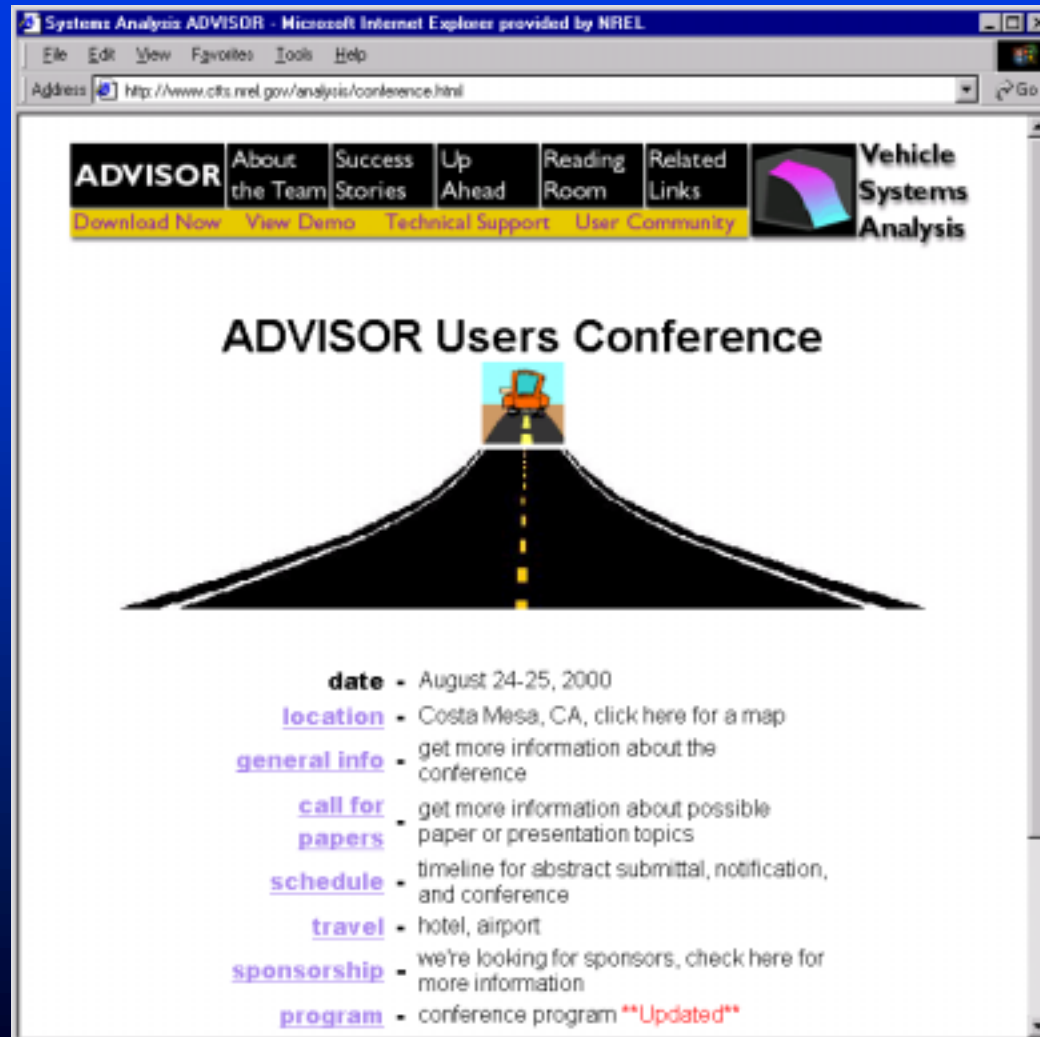
(as of 12/2/99)



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ADVISOR Users Conference: August 2000




Systems Analysis ADVISOR - Microsoft Internet Explorer provided by NREL

Address <http://www.cts.nrel.gov/analysis/conference.html>

ADVISOR About the Team Success Stories Up Ahead Reading Room Related Links
Download Now View Demo Technical Support User Community

Vehicle Systems Analysis

ADVISOR Users Conference



- date** - August 24-25, 2000
- location** - Costa Mesa, CA, [click here for a map](#)
- general info** - get more information about the conference
- call for papers** - get more information about possible paper or presentation topics
- schedule** - timeline for abstract submittal, notification, and conference
- travel** - hotel, airport
- sponsorship** - we're looking for sponsors, check here for more information
- program** - conference program ****Updated****



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ADVISOR Users Conference: Program

Program	
Thursday, August 24, 2000	
8:15	Registration & Continental Breakfast
9:00	Opening Address -Keith Wipke, National Renewable Energy Laboratory
9:15	Partnering with the Auto Industry The Rapid Development of an Electric Vehicle -Andreas Vlahinos, David Rush, Transportation, Design & Manufacturing CO Co-Simulation of ADVISOR and Saber - A solution for total vehicle energy management simulation -John MacBain, Delphi Automotive Comparison of fuel efficiencies and fuel flexibility of small automotive vehicles -Robert Apter, John Reuhl, NEVCOR
10:45	Break
11:00	Cosimulation: Partnering with the Software Industry I Optimization and Thermal Modeling Implementing Optimization in ADVISOR Using the VisualDOC API -John Garcelon, Vanderplaats Research & Development Detailed Vehicle Thermal Systems Modeling in ADVISOR through Integration with Flowmaster2 -Jason Burke, Flowmaster
12:00	Lunch, Poster sessions
13:30	DOE perspective on ADVISOR -Bob Kost, Department of Energy
14:00	HIL and Forward-Looking Simulations Coupled with ADVISOR Using Models for Hardware-in-the-Loop (HIL) and Systems Studies -Mike Dvobe, Argonne National Laboratory A Design Methodology for Diesel-Based Hybrid Powertrains -George Delagrammatikas, Dennis Assanis, University of Michigan
15:00	Break
15:15	New Concepts from Universities A hybrid-propulsion powertrain with planetary gear set: simulation results and a design approach -Marco Santoro, Dresden University of Technology, Leone Marfellucci, University of Rome Use of ADVISOR for simulation of a Hybrid Electric Vehicle with a Stirling Engine as the Auxillary Power Unit -Luis Figueroa, University of Calgary Development of an ADVISOR Simulation Model for GW FutureTruck Vehicle -Mohd-Syafuddin Mohd, George Washington University
16:45	Q&A with the ADVISOR team Moderator Terry Penney, NREL
17:30	Reception and Banquet Keynote Presentation: Toyota's US Prius -Mark Amstock, Toyota
Friday, August 25, 2000	
8:00	Continental Breakfast
8:30	Validation, Vehicle Development, and Applications Simulations of heavy-duty transit buses -Alain Jullien, Jean Bavard, Alstom



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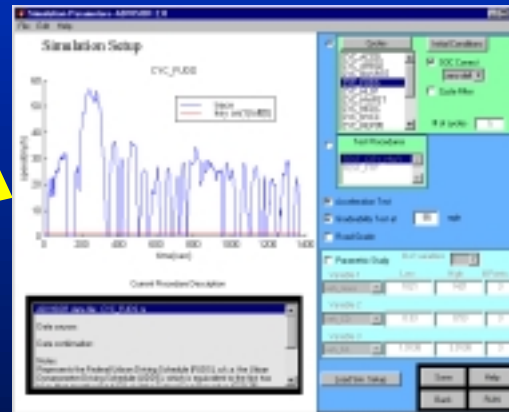


Three Main ADVISOR Screens (Roadmap)

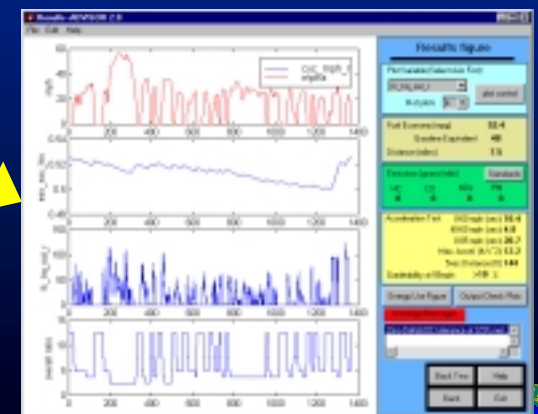
Vehicle Input



Simulation Setup



Results



ADVISOR Demonstration

ADVISOR 2.2
Advanced Vehicle Simulator

Engine Torque (Nm)

200
150
100
50

00 2000 2500 3000 3500 4000
Engine Speed (rpm)

Start Help Exit

NREL

DEPARTMENT OF ENERGY
UNITED STATES OF AMERICA



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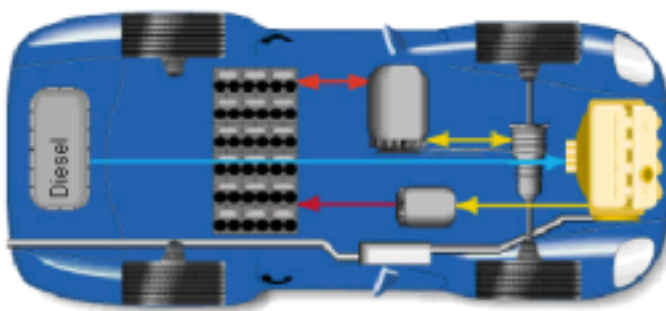


Vehicle Input Screen

Vehicle Input--ADVISOR 2.1

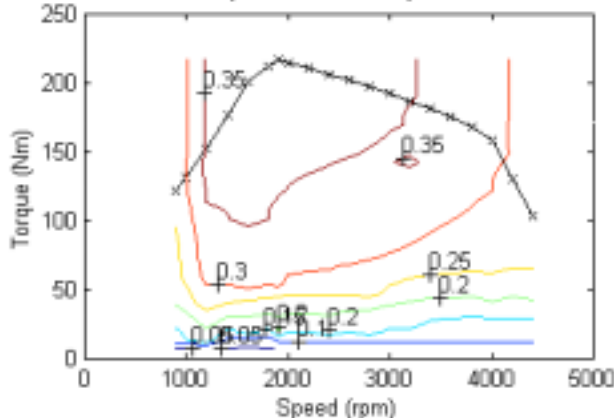
File Edit Help

Vehicle Input



fc_efficiency

Fuel Converter Operation
Volkswagen 1.8L Turbo Diesel Engine f/ ORNL



Scale Components

	max pwr [kW]	peak eff	mass [kg]
Fuel Converter	67	0.39	214
Generator	47	0.95	55
Torque Coupling		1	
Motor/Controller	75	0.92	91
Exhaust Aftertreat			17
Transmission		0.96	50
Wheel/Axle			0
Vehicle			592
Energy Storage			275

Vehicle Input Parameters:

- Load Vehicle: gui_defaults_in
- Auto-Size
- series
- Fuel Converter: FC_C167_emis
- Generator: GC_ETAS95
- Torque Coupling: TC_DUMMY
- Motor/Controller: MC_AC75
- Exhaust Aftertreat: EX_SI
- Transmission: TX_1SPD
- Wheel/Axle: WH_SMCAR
- Vehicle: VEH_SMCAR
- Energy Storage: ESS_PB25
- Powertrain Control: PTC_SER
- Accessory: ACC_HYBRID
- Cargo Mass: 136
- Calc. Mass: 1430
- override mass: 1

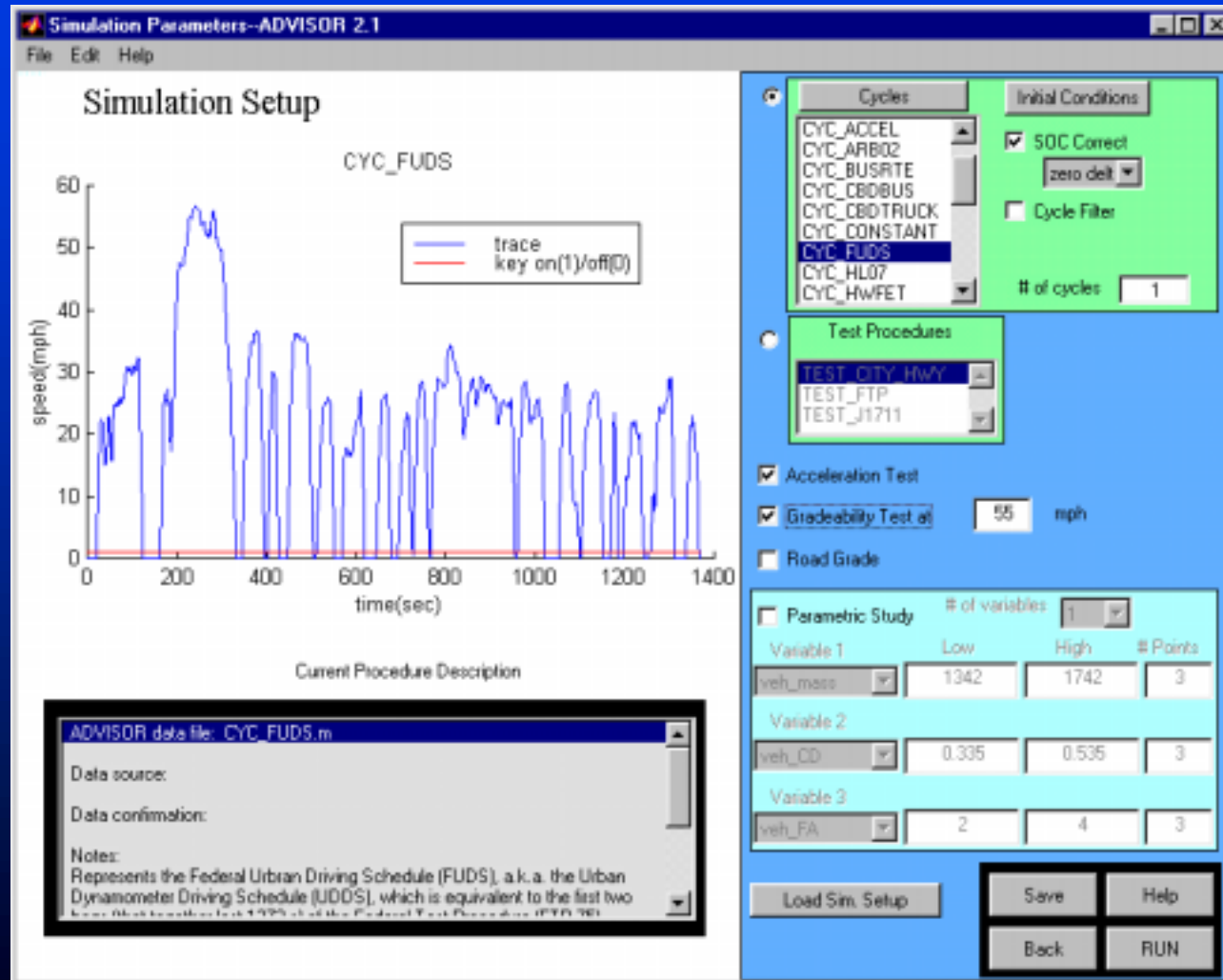
Variable List

- acc_elec_eff
- acc_elec_pwr
- acc_mech_eff
- acc_mech_pwr
- acc_mech_trq
- acc_proprietary
- acc_validation
- acc_version

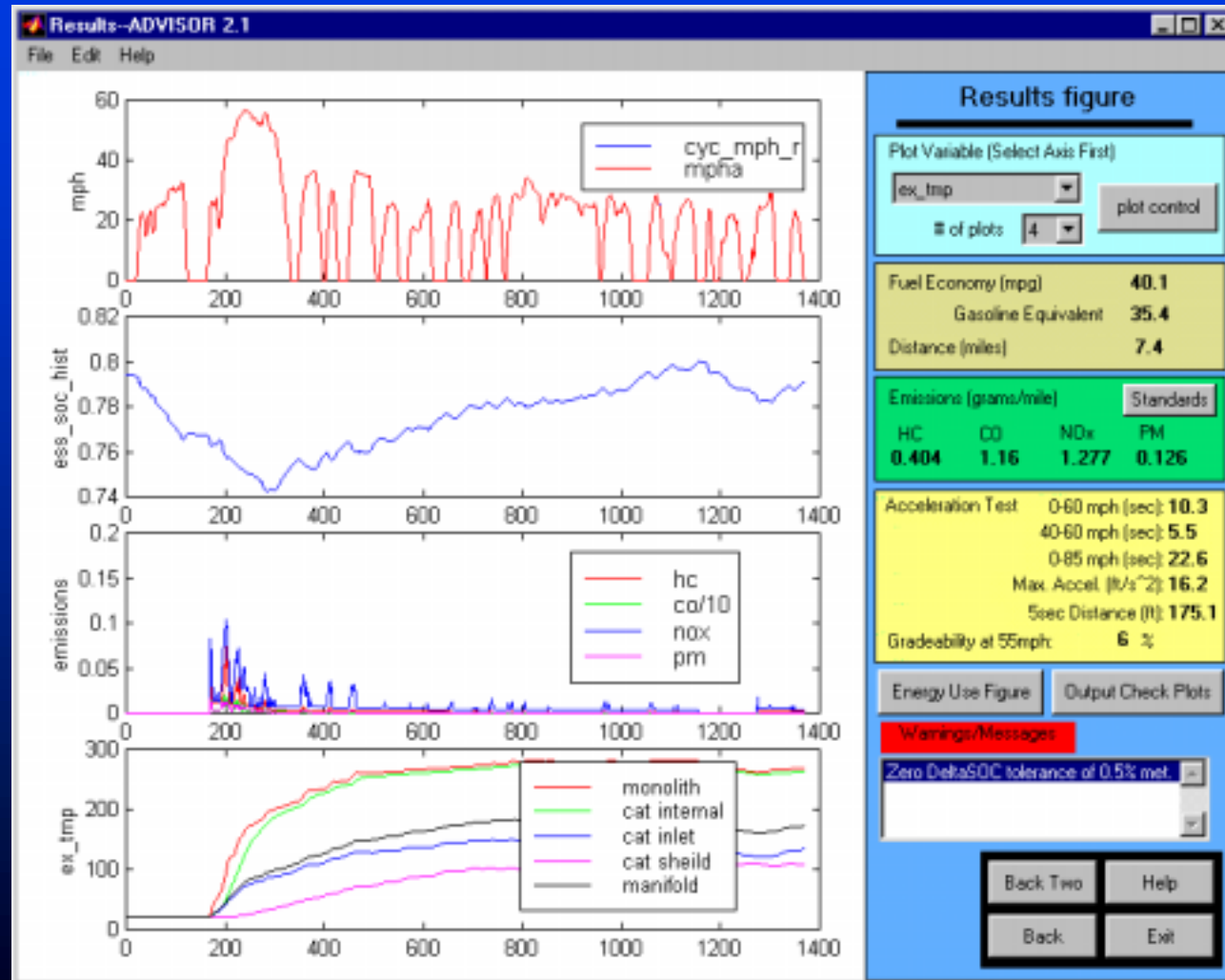
Save Help

Back Continue

Simulation Setup Screen

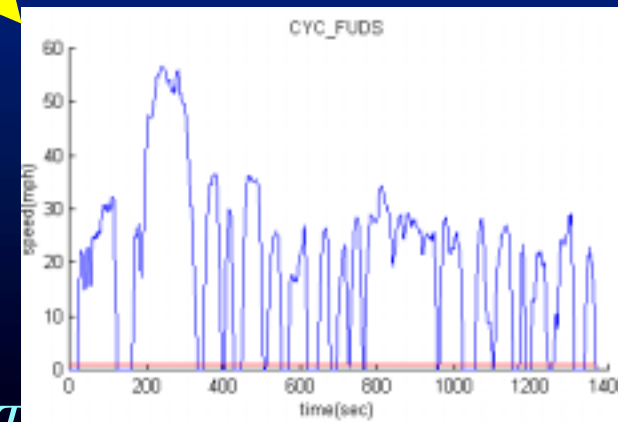
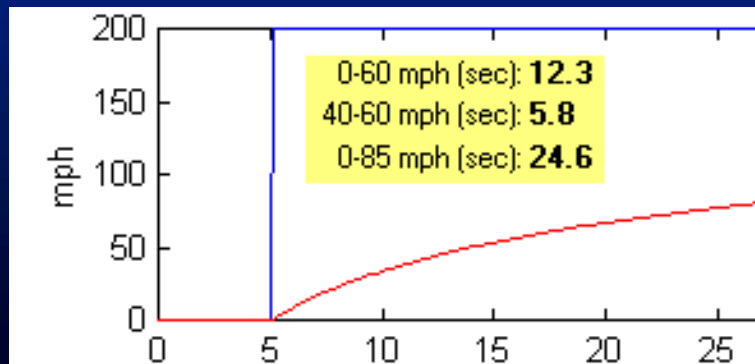
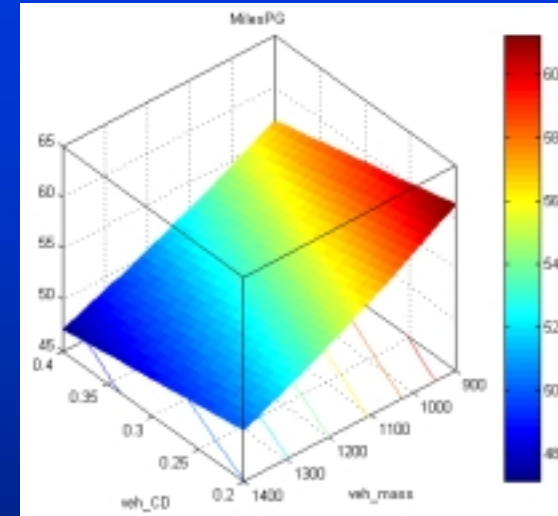


Cycle Results Screen



Types of Simulation Tests Possible

- Parametric sweeps
- Drive cycles
- Acceleration and grade tests



“Test Procedures” Currently Available

FTP Test

FTP Results-ADVISOR 2.0

FTP Results

Fuel Economy (mpg)

mpg	42.1
Gasoline Equivalent	37.2

Emissions (grams/mile)

	HC	CO	NOx	PM
Bag 1 (0-505 sec)	0.673	2.078	1.752	0.203
Bag 2 (505-1374 sec)	0.165	0.240	0.811	0.056
Bag 3 (1374-end sec)	0.156	0.266	0.956	0.06
Weighted Total	0.268	0.633	1.046	0.088

Note: Total emissions is weighted as follows:
 $Total = (0.43 * Bag1 + 0.57 * Bag2 + 0.43 * dist1 + 0.57 * dist3)$ where Bag* is in grams and dist* is in miles

Combined City/Highway

City/Highway Results-ADVISOR 2.0

Combined City/Highway Cycle Results

Fuel Economy (mpg)

	City	Highway	Combined
mpg	43.2	59	49.1
Gasoline Equivalent	42.7	58.4	48.6

Emissions (grams/mile)

	HC	CO	NOx	PM
City	0.252	0.887	0.231	0
Highway				
Ratio of Hwy/City NOx			0.67	

Note: City values based on one cold-start FTP-75 cycle. Highway values based on one hot-start HWFETS cycle. Combined fuel economy $FE_{comb} = 1 / (1/55/MPG_{city} + 1/45/MPG_{hwy})$

Real World

Real World Test Procedure Setup

Approximate run times: 2/14 minutes conv, 2/15-day (11/77K FUDS run) 6/50 min for hybrid, 2/16-day (24/200K FUDS run)

Choose Time Period (required input):

2-day set of cycles

16-day set of cycles

Specify Ambient Temperature (C)

Optional comparison:

Compare to FTP?

Specify Length of Cold Soak (hrs)?

Default tracking of fuel economy, emissions, and miles travelled.

Additional Variables to Track:

Available Variables:

Variables to track:

Buttons: Help, Back, Run

SAE J1711 Test Procedure Results

Final

Fuel Economy (mpg)	HC	CO	NOx	PM
26.7	0.345	2.181	0.595	0

Final Cycle level

Mode	MPG	HC	CO	NOx	PM
EV	23.6	0.458	4.846	0.774	0
HEV	31.7	0.197	0.794	0.182	0
ICE	28.6	0.284	0.882	0.595	0
ICE	28.9	0.305	1.335	0.737	0

Partial Charge Test: PCT HEV, PCT EV

Full Charge Test: PCT HEV/F, PCT HEV/B

SAE values for PCT HEV (allowable ICC(mile))

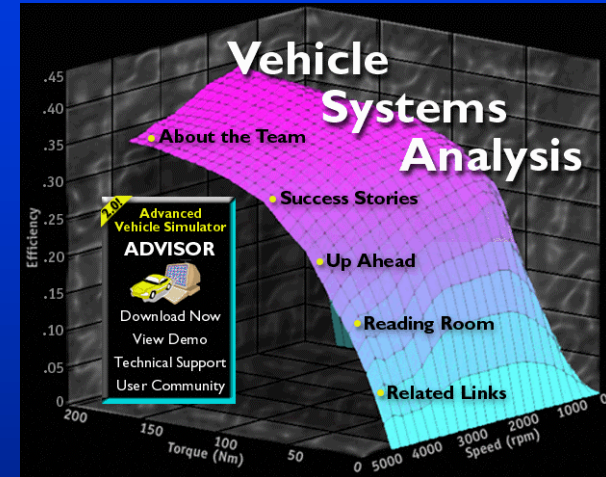
Mode	EV	EV	EV	EV	EV
FUEI	0.504	0.549	0.525	0.525	0.525
HAUFET	0.54	0.535	0.518	0.518	0.518
ICE	0.54	0.574	0.565	0.561	0.567
ICE	0.54	0.624	0.627	0.494	0.474

SAE J1711 HEV Test Procedure



Software Availability on Web

- NREL's Vehicle Systems Analysis web site launched in September 1998
- ADVISOR 2.2 available for free after filling out simple form (incl. source code)
- 'Forum' has bulletin area for questions to be answered and files to be shared
- Documentation viewable from web site
- Reading room has all papers and presentations from team



Keith Wipke, Matt Cuddy, Sam Sprik, Steve Burch, Valerie Hovland, Tony Markel.

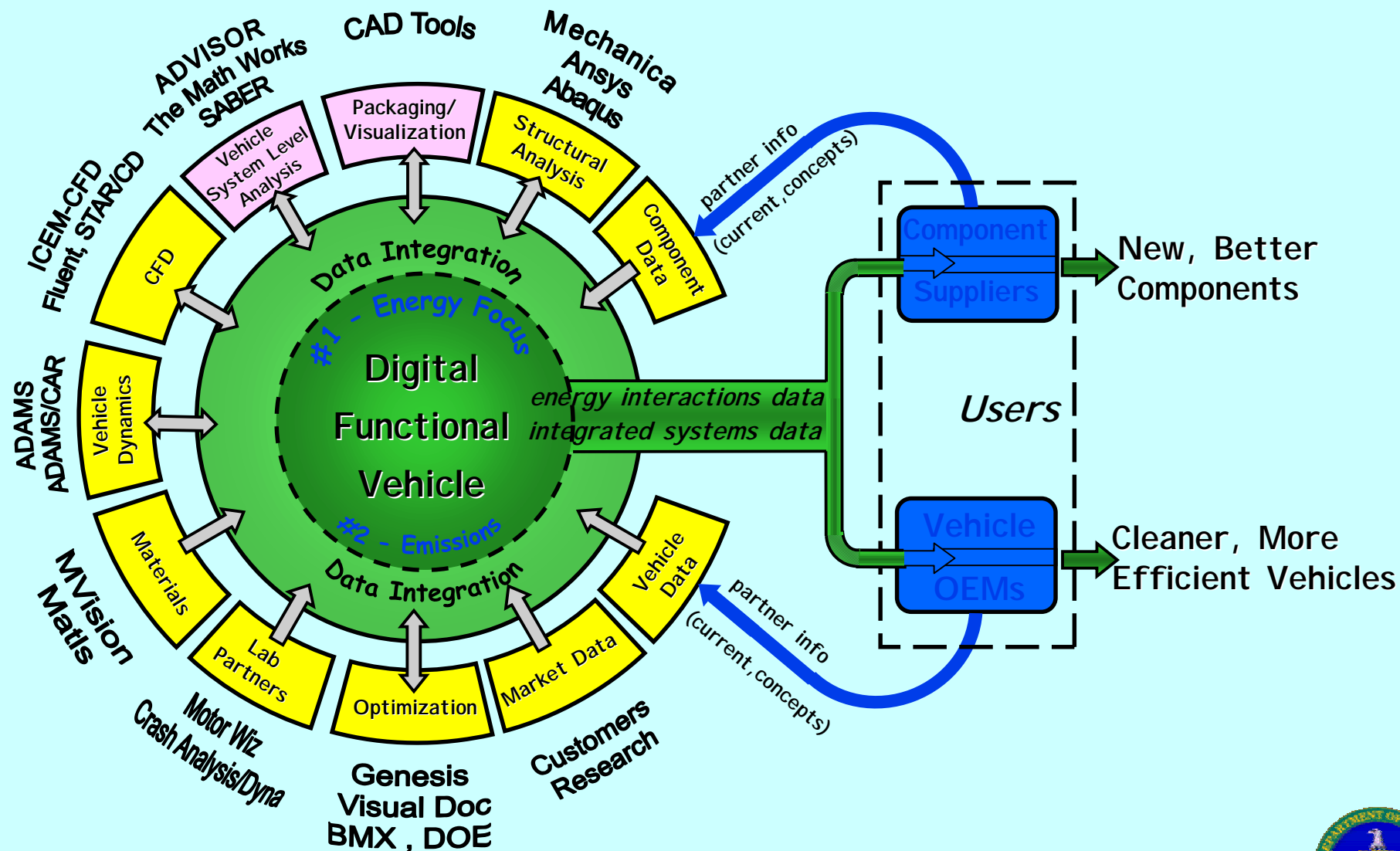
Not pictured: Matt Keyser, Desikan Bharathan



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Example of Linkage with Packaging



Loading ADVISOR Vehicle into Pro/HEV

Pro/HEV 1.1 - Netscape

File Edit View Go Communicator Help

Back Forward Reload Home Search Netscape Print Security Shop Stop

Location: <http://192.174.54.60/prohev/prohev.htm>

NATIONAL RENEWABLE ENERGY LABORATORY

Pro/HEV

DOE | NREL | ADVISOR

FILE

- ▶ [Load HEV]
- ▶ [Save HEV]
- ▶ [Load Defaults]
- ▶ [Clear]

ANALYSIS

- ▶ [Configure]

EDIT

Design Summary:

Vehicle Name:

Energy Storage Name:

Wheel-axle Name:

ADVISOR Data:

Vehicle Class: Number of passengers:

Wheelbase: mm Number of modules:

Drivetrain Type:

Track (front): mm

Track (rear): mm

Last updated Monday, November 15, 1999 09:29:14

[Pro/HEV Site Map](#) || [Help](#) || [Search](#) || [Email](#) || [Design Summary](#)

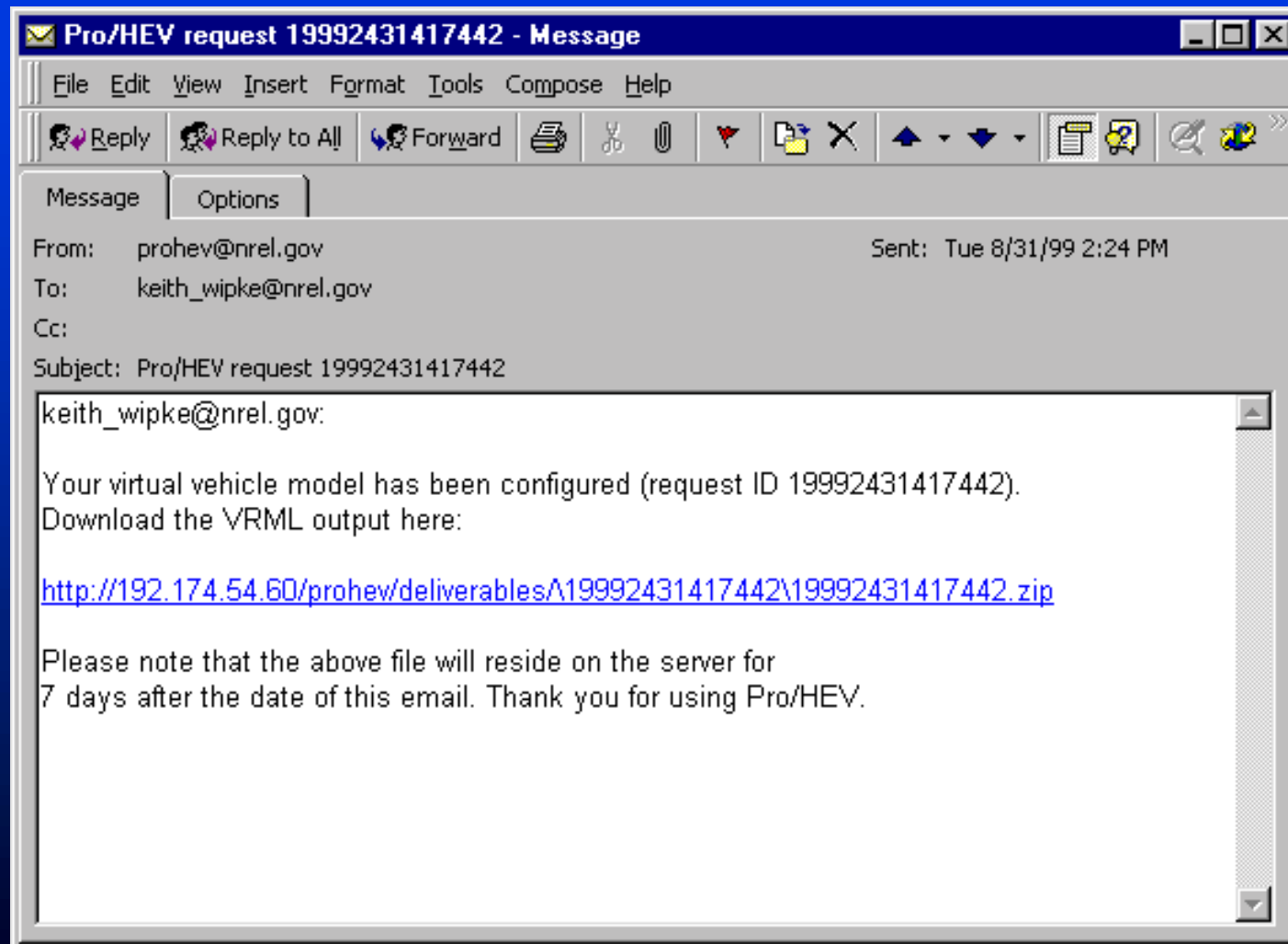
Contact: NREL, 1617 Cole Boulevard, Golden, CO 80401-3393 prohev@nrel.gov



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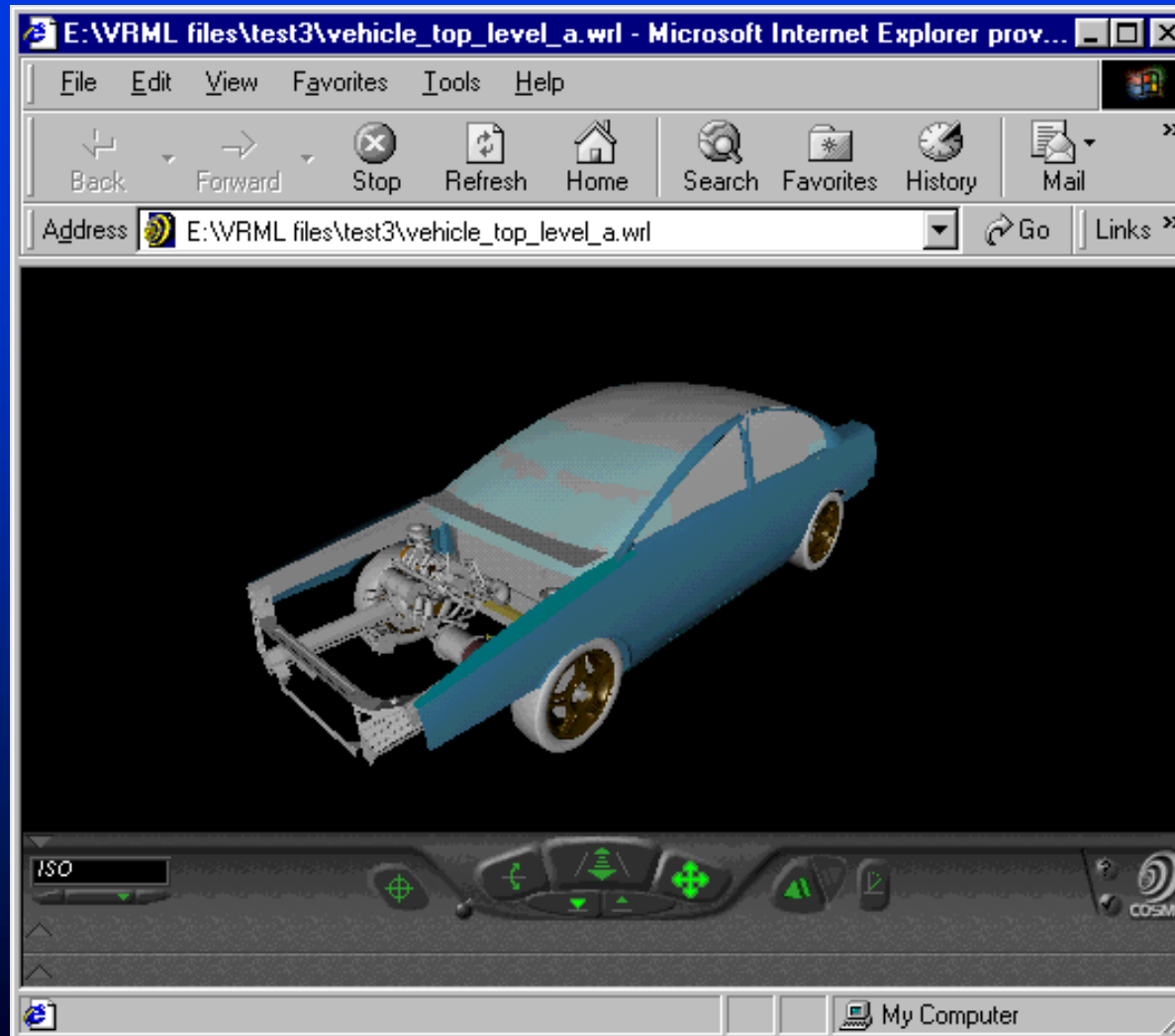
E-mail notification of VRML files



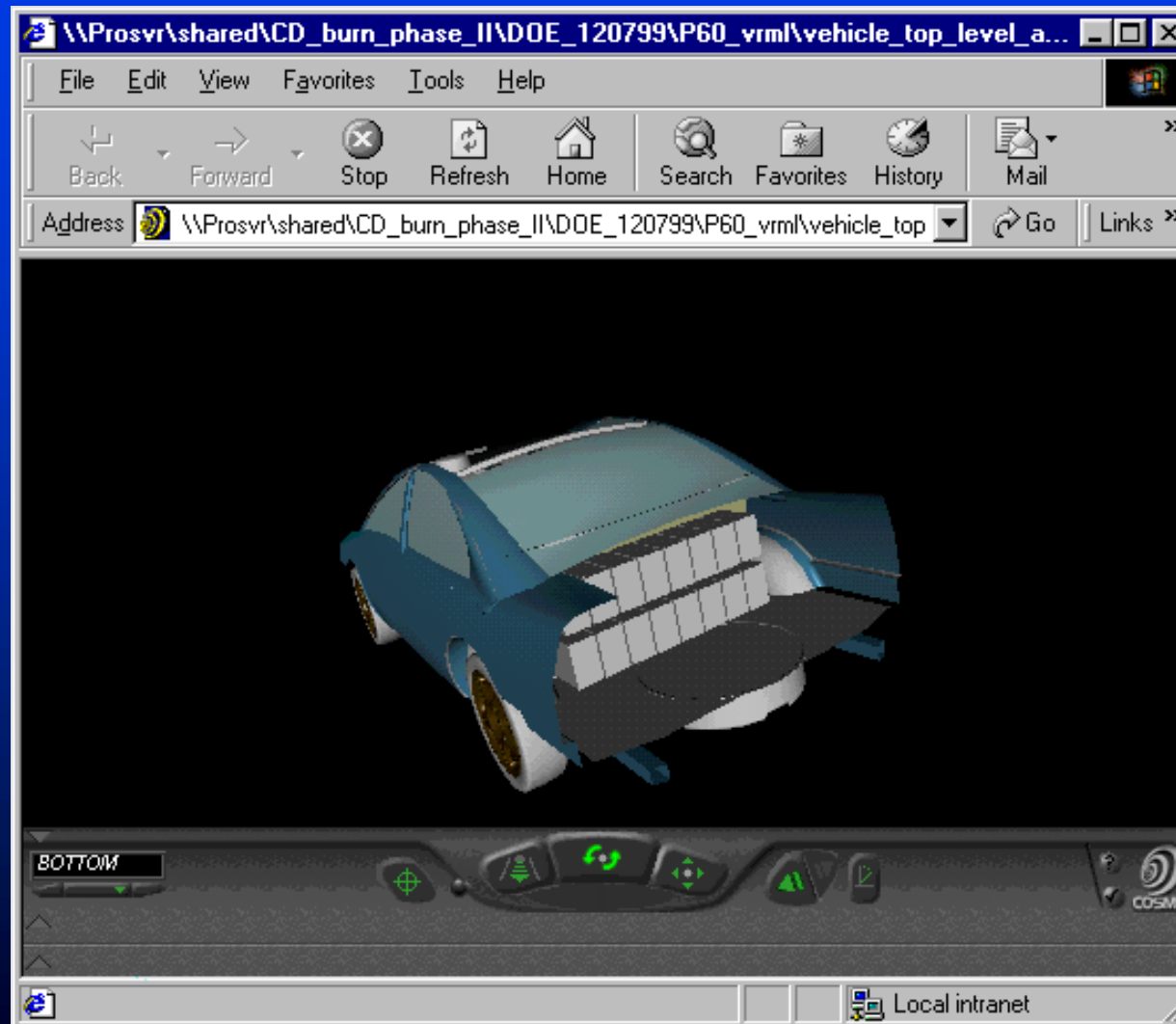
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Visualizing VRML Vehicle in Browser

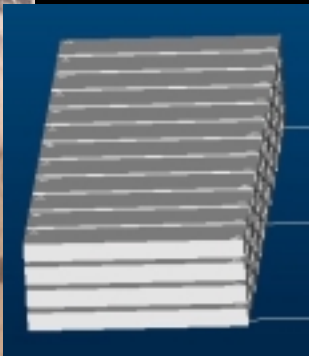


Visualizing VRML Vehicle in Browser

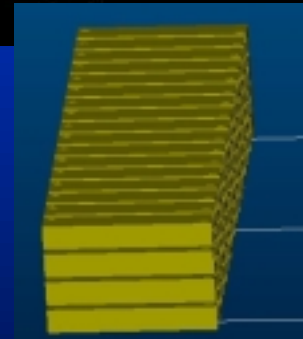


Battery Packaging Comparison from Previous Study (for illustration purposes)

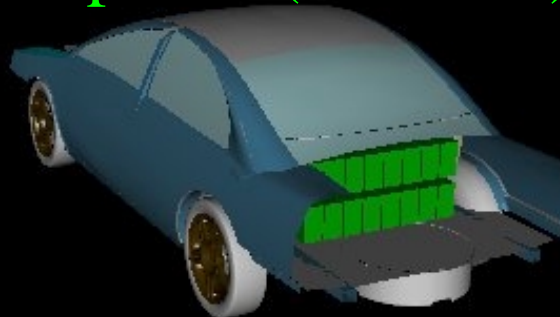
Prius (NiMH)



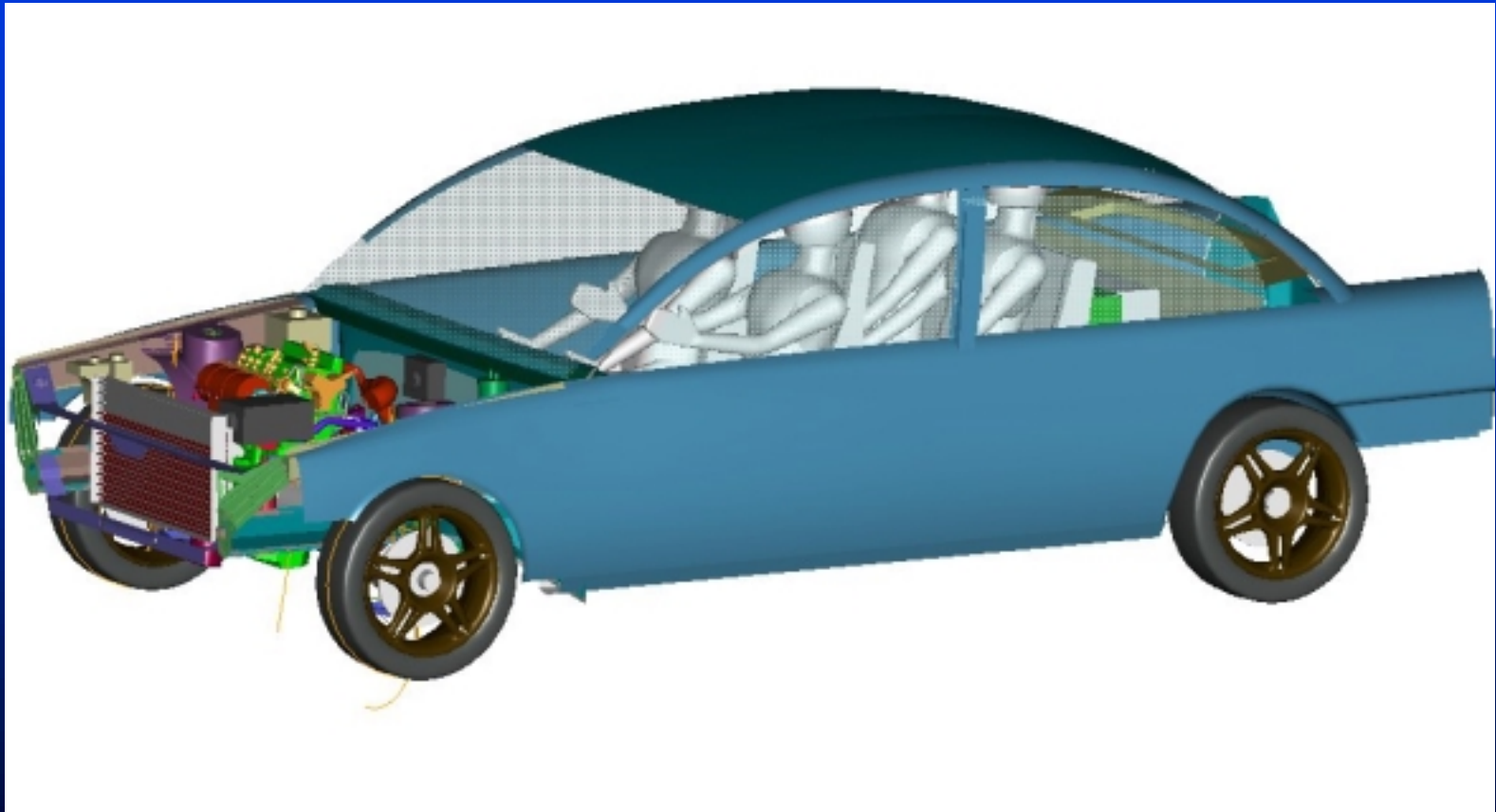
Battery "A" (Li-ion)



Optima (Pb-Acid)



Full Parametric Vehicle Assembly also Includes Geometry Useful for Many Groups at NREL





Outline: Interfacing ADVISOR and ADAMS/Car

- Two interface approaches will be used:
 - ADAMS/ADVISOR Co-simulation
 - Export to ADAMS/Car
- Each approach has its own advantages and serves different simulation purposes.



ADAMS/ADVISOR Co-simulation

- What?
 - Linking ADAMS/Car full vehicle model with ADVISOR model.
 - Both ADAMS and Simulink solvers run together. Information passed back and forth between the two at each time step.
- How?
 - ADAMS/Car full vehicle model using customized powertrain template.
 - Modified ADVISOR model to work with ADAMS/Car model.

ADAMS/ADVISOR Co-simulation

- Why?
 - Simulate 4WD/AWD powertrains
 - torque split can be actively controlled by ADVISOR
 - Vehicle handling/dynamics with new CM from ADVISOR
 - Can look at stability issues relating to battery placement
 - Calculate energy losses during handling/durability events
 - useful for trying minimizing losses for maximum fuel efficiency
 - Integrate accessory loads (like electric power steering) and look at their energy impact vs. performance
 - Trade-offs to accurately assess impact of vehicle/component mass reduction and evaluating effect on dynamic performance
 - Perform anything you would normally do in ADAMS/Car, but using and advanced powertrain from ADVISOR



ADAMS/ADVISOR Co-simulation

- Overview

Preprocessing

Pro/Engineer

Mass, Inertia
& Geometry

Analysis

ADAMS/Car
Full Vehicle Model

Customized
Powertrain Template

Co-simulation

ADVISOR

Postprocessing

Handling Results,
Animations

Energy losses, Emissions,
Fuel efficiency, etc.

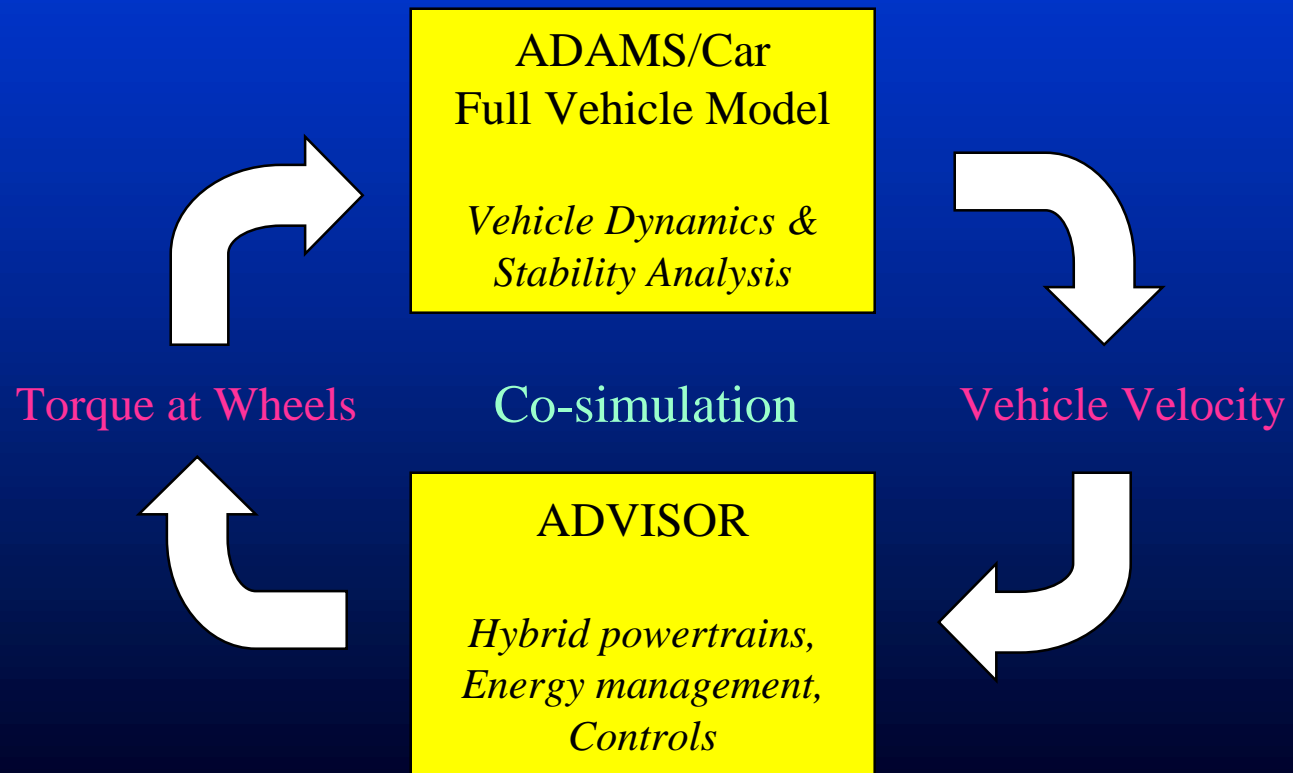


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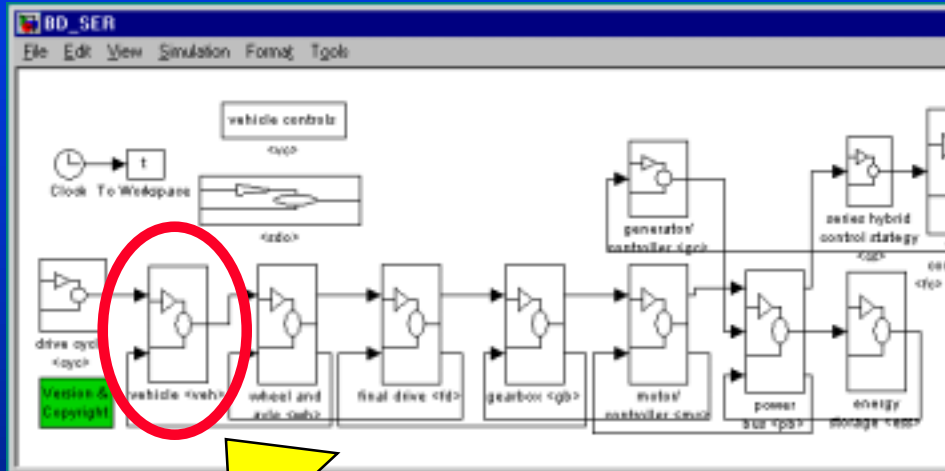
ADAMS/ADVISOR Co-simulation

- Information Flow
 - The major variables exchanged are shown below. Additional information will also be exchanged.



ADAMS/ADVISOR Co-simulation

- Exporting ADAMS/Car Plant to Simulink



Block Parameters: ADAMS Plant

MDI/ADAMS Plant (mask)
Simulate any MDI/ADAMS plant model either in ADAMS/Solver form (.adm file) or in ADAMS/View form (.cmd file)

Parameters

ADAMS install directory
ADAMS_dir

User executable (opt.: if blank - use standard)
ADAMS_exec

Initial Static Simulation Flag
ADAMS_static

ADAMS model file prefix
ADAMS_prefix

ADAMS/View input names
ADAMS_inputs

ADAMS/View output names
ADAMS_outputs

ADAMS/Solver in/output IDs
ADAMS_up_ids

Direct feedthrough number
0

Output files prefix (opt.: if blank - no output)
[plant_out]

Output step size
0.005

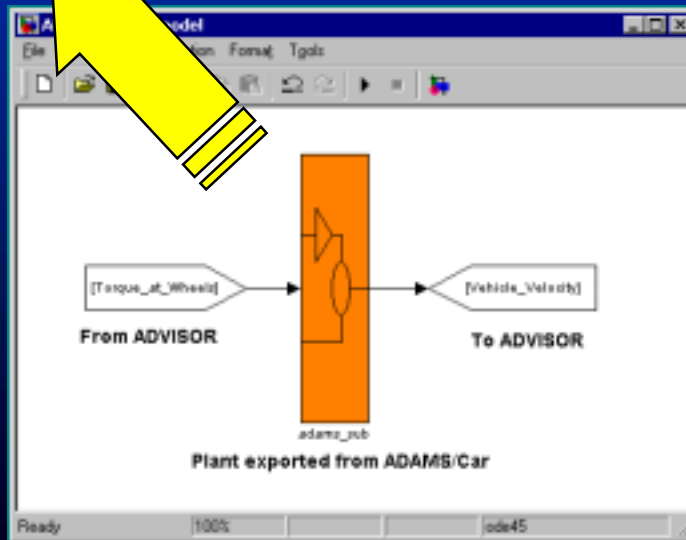
Simulation mode: discrete

Animation mode: batch

Initialization mode: automatic

Initialization commands
[]

Buttons: OK, Cancel, Help, Apply



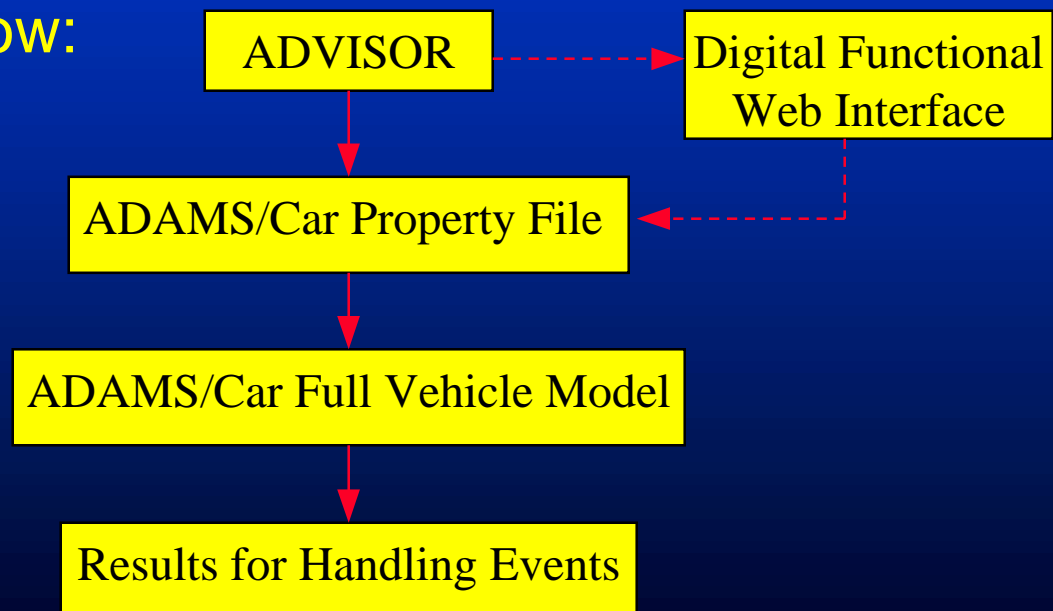
Export to ADAMS/Car

- What?
 - ADAMS/Car full vehicle model with mass and inertia properties exported from ADVISOR
 - One way information flow to ADAMS/Car
- How?
 - Output mass and inertia properties from ADVISOR to ADAMS/Car.
 - Optionally, geometry may be specified in web interface
 - Run standard handling maneuvers in ADAMS/Car.

Export to ADAMS/Car

- Why?
 - Faster simulations
 - Quick estimate of handling performance of hybrid vehicle
 - Example: allows analysis of battery pack location (often a large mass) and effect on handling

- Information flow:



Conclusions

- ADVISOR 2.2 is a user-friendly simulation tool available to the public through the web
 - www.nrel.gov/transportation/analysis
- Widespread usage of the model globally has led to a large database of components and vehicles
- NREL is working with industry to link ADVISOR up to tools they use, such as:
 - Pro/E (visualization, packaging)
 - Visual-Doc (Optimization)
 - SABER (electrical)
 - ADAMS/Car (vehicle dynamics)
- Looking for input from active ADAMS users on how they might benefit from and guide this linkage with our advanced powertrain modeling linkage (ADVISOR)

