25 Years of Research Excellence 1977-2002

National Renewable Energy Laboratory

Systems Approach in the Vehicle Technologies Program

Terry Penney, Technology Manager

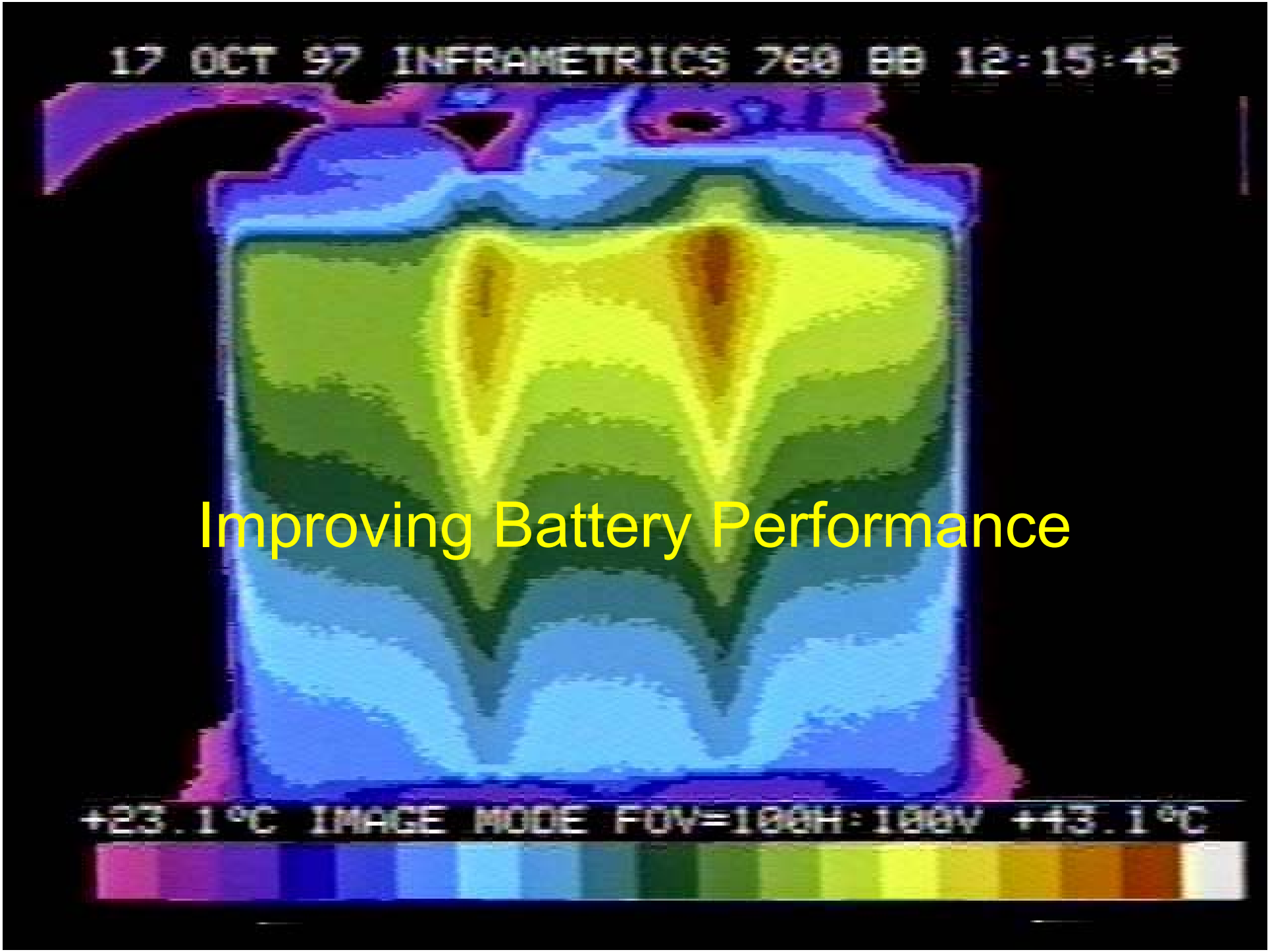
National Renewable Energy Laboratory

Presented at: Systems Analysis Approach to Solar Program Planning and Management Meeting

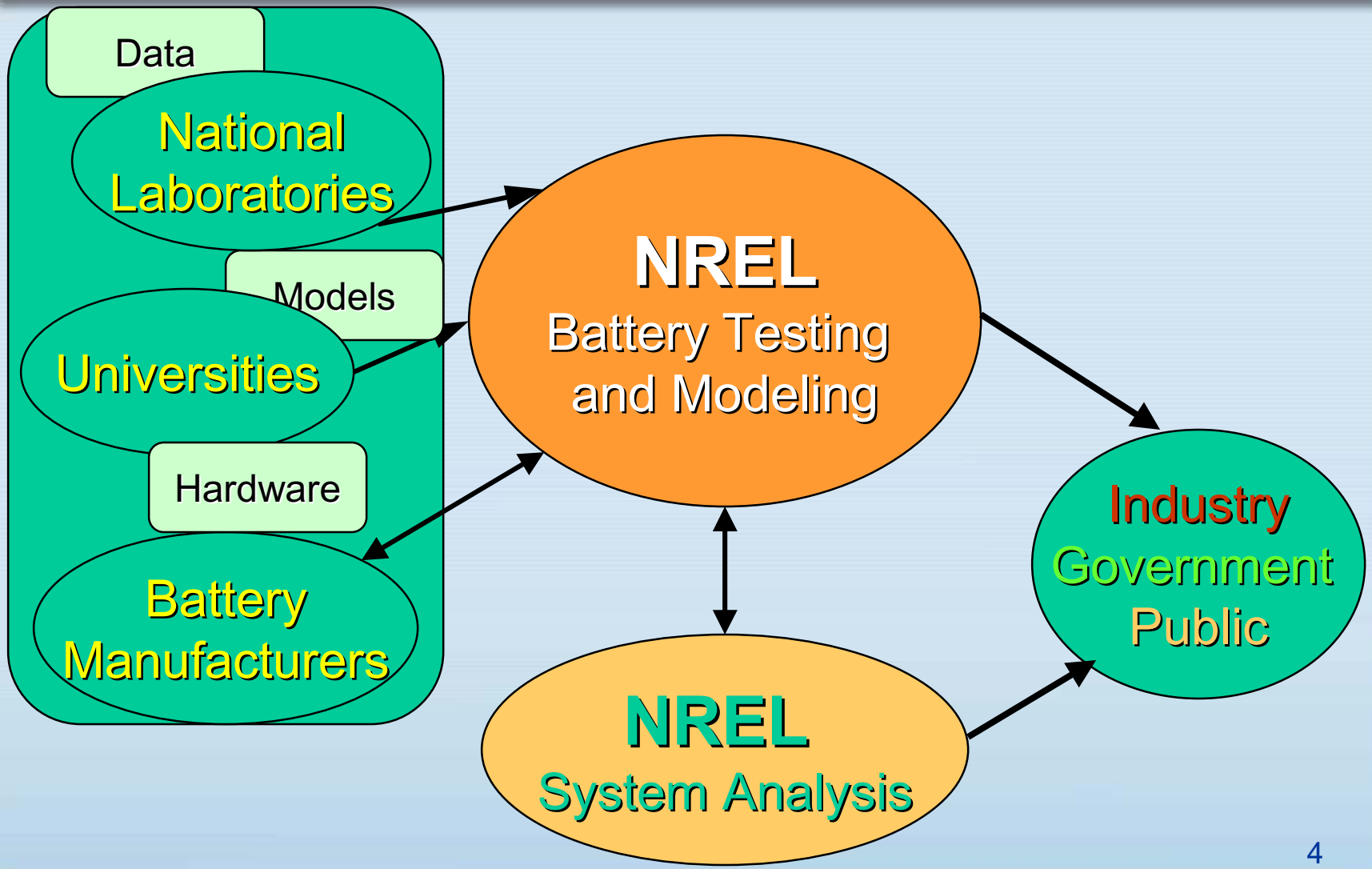
Dec. 17-18, 2002

Important Steps in Implementing Systems Analysis Tools

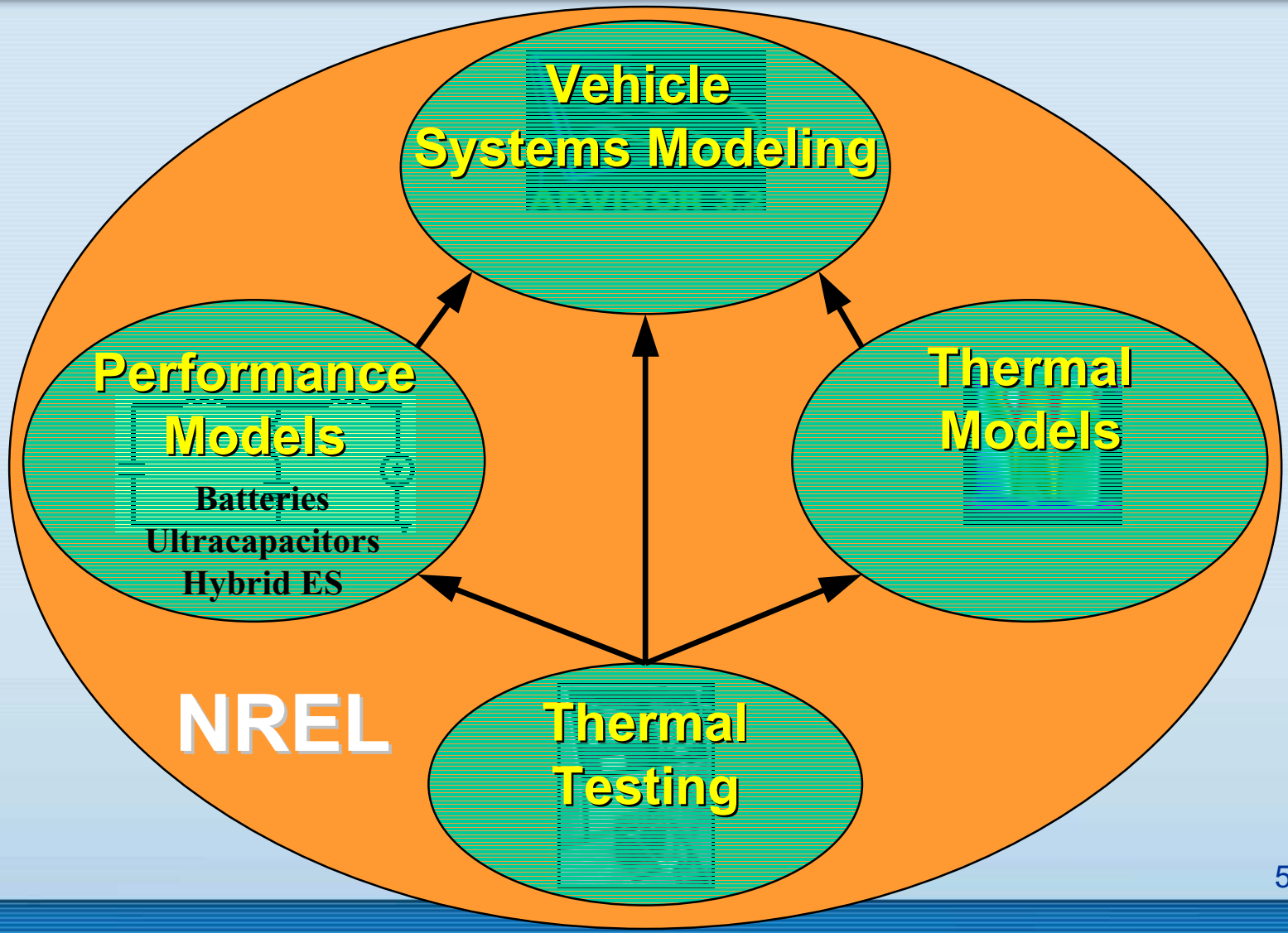
1. Understand what questions should be asked
2. Answer the questions
3. Show technical trade-offs through partnerships
4. Use industry tools and co-simulation if possible
5. No one system tool gives all the answers – use a suite of tools
6. If analysis doesn't show unique insight, then it doesn't earn value


17 OCT 97 INFRAMETRICS 760 BB 12:15:45
Improving Battery Performance
+23.1°C IMAGE MODE FOV=100H·100V +43.1°C

Integrated Battery Modeling and Testing Activities with others organizations



Integrated Battery Modeling and Testing Activities at NREL



Collaborating with Industry

PNGV PolyStor

GM

OPTIMA BATTERIES

AeroVironment

Department of Energy, United States of America

Ford

Johnson Controls

GNB Technologies

Texas Instruments

DaimlerChrysler

Compact Power

University of Toledo

SAFT

Energy Conversion Devices, Inc.

Ovonic NiMH

The Advanced Lead-Acid Battery Consortium — ALABC

Optimum charging

BOLDER Technologies

Trojan Battery Company

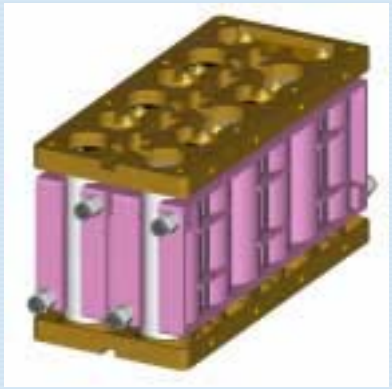
Ford

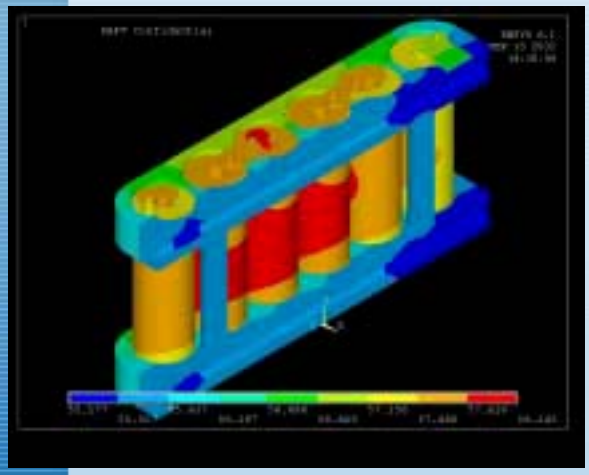
EV applications

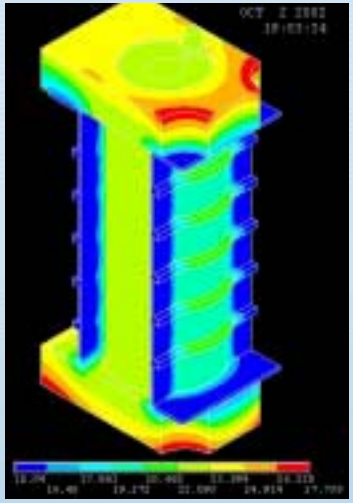
RAYOVAC

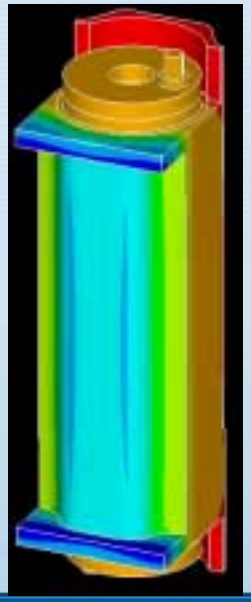
Zinc-Air

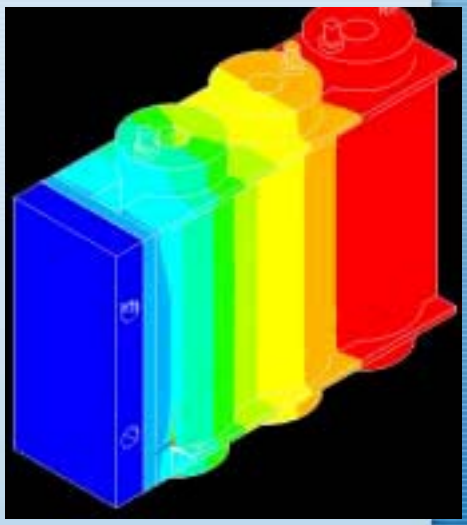
Improving Thermal Design



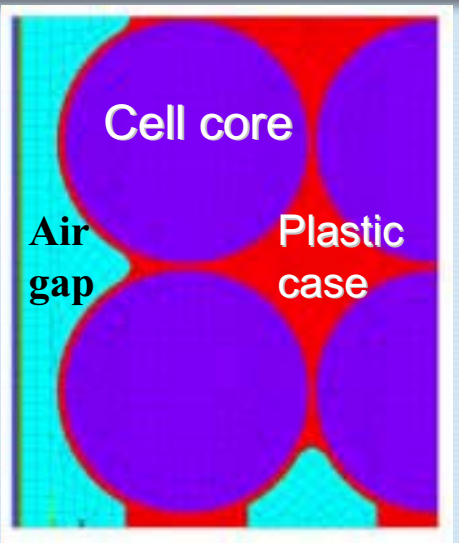








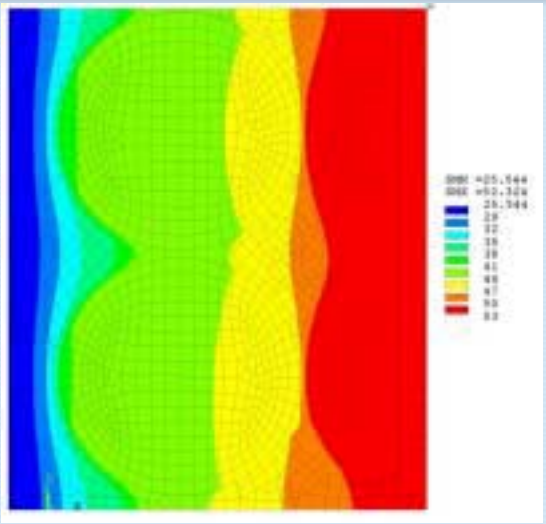
Thermal analysis could improve module thermal performance

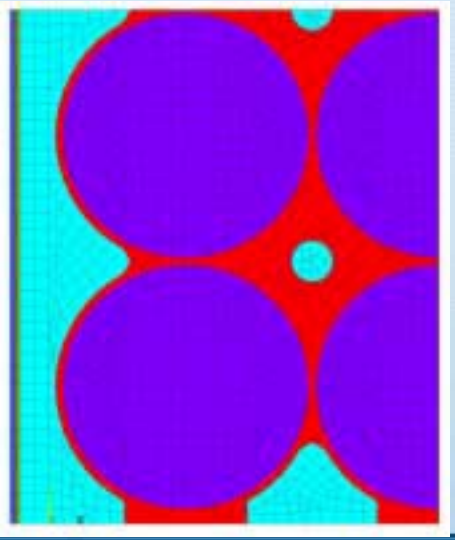


No Holes

Tmax = 53ºC

Delta Tcore = 13ºC

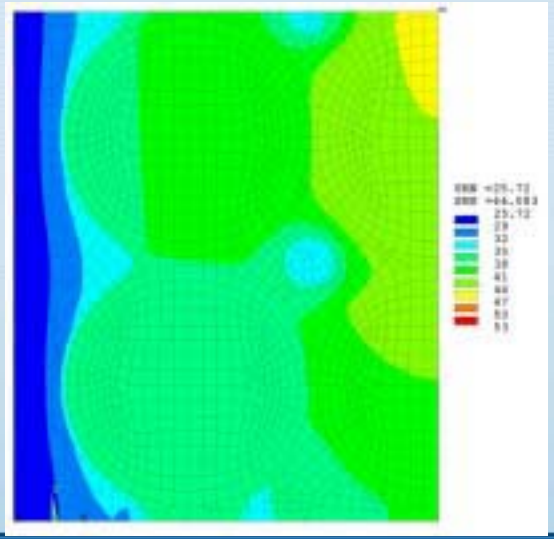




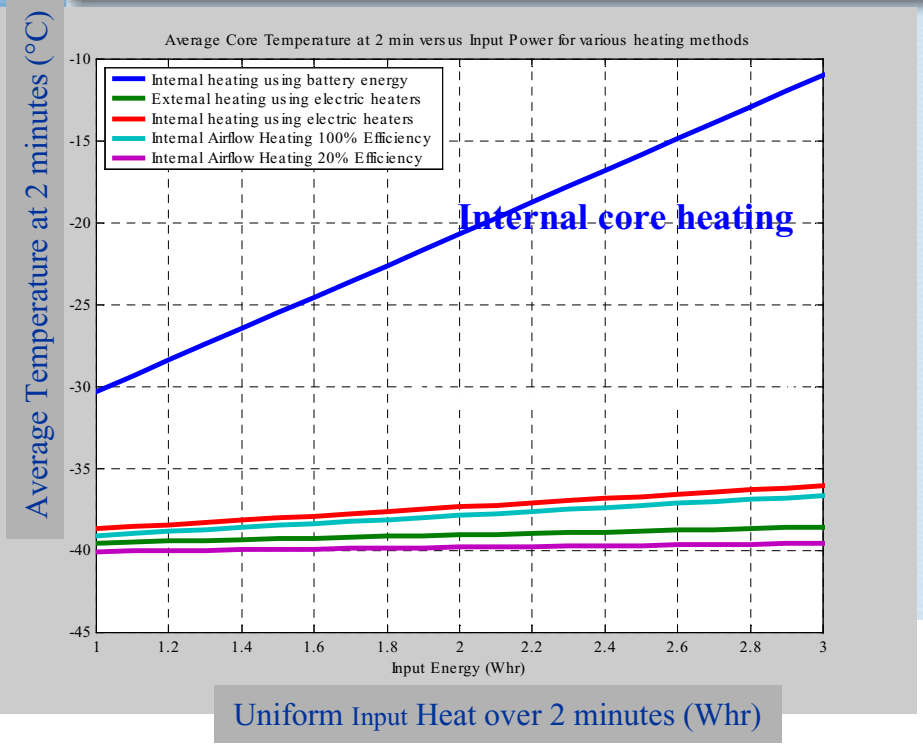
With Holes

Tmax = 44ºC

Delta Tcore = 9ºC



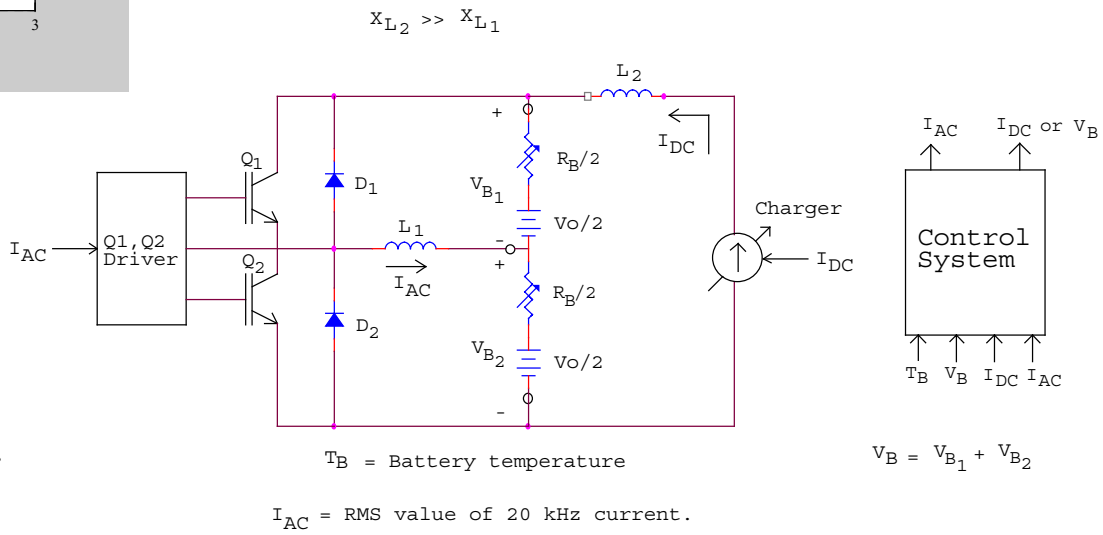
Evaluating High Frequency AC Heating of Batteries at very Cold Temperatures



Uniform Input Heat over 2 minutes (Whr)

- Analysis has shown that core heating batteries is the most efficient and effective method.
- Core heating can be achieved by applying high frequency AC power through battery terminals
- Because of high battery resistance at low temperature battery heat up

- We are working with University of Toledo to evaluate various AC heating techniques
- Initial results show that a non-operation lead acid battery at -40°C can be warm up quickly to deliver satisfactory power

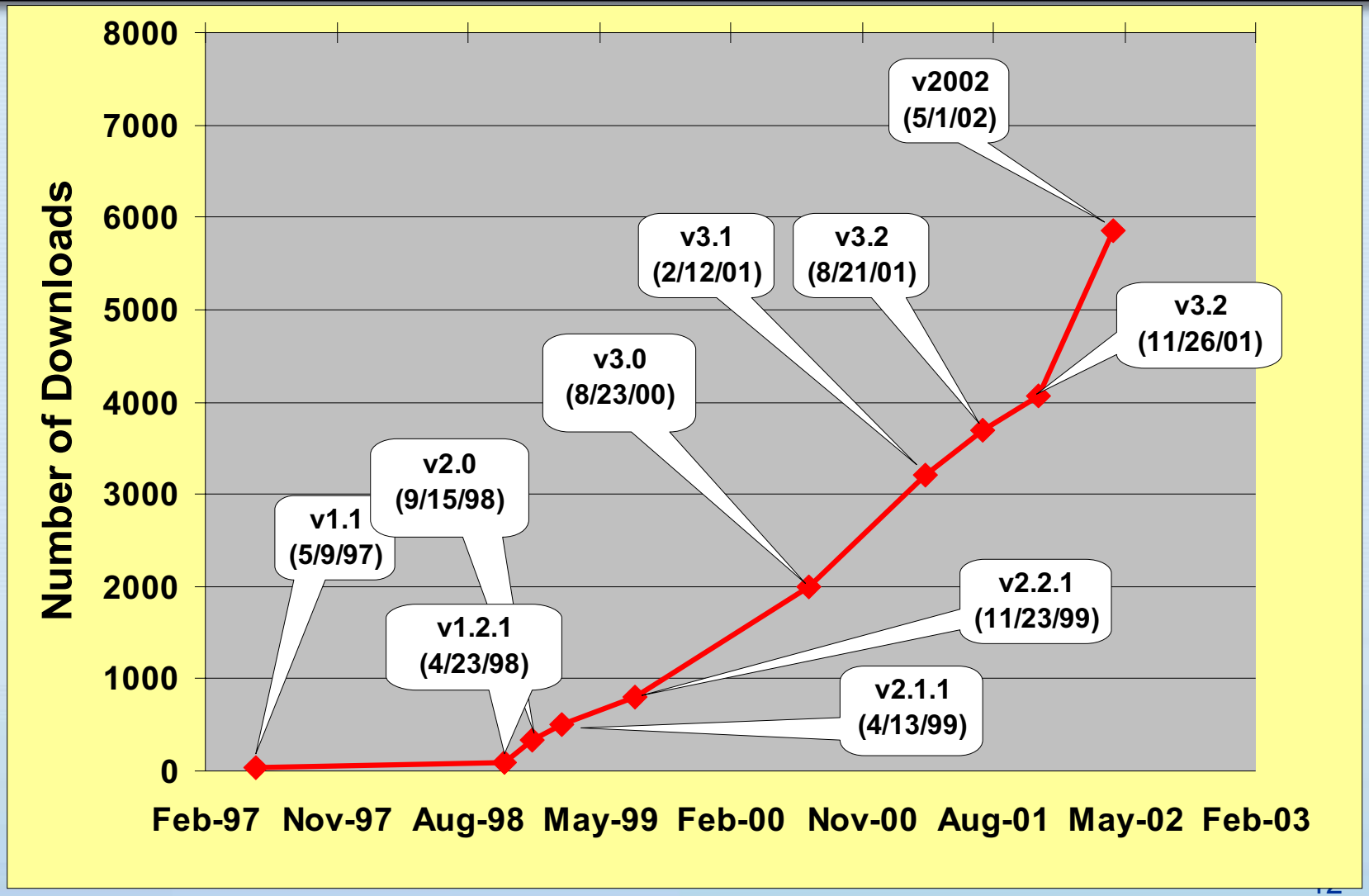



ADVISOR and Technical Targets Tool

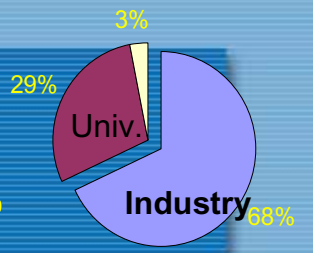
Introduction to ADVISOR

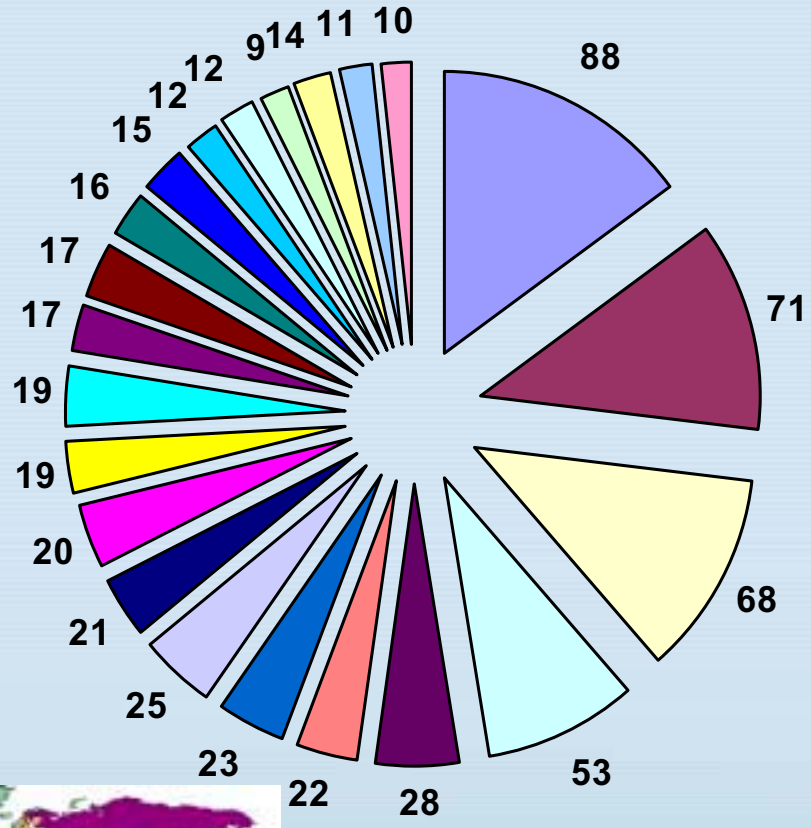
- ADVISOR = ADvanced VehIcle SimulatOR
  - simulates conventional, electric, and hybrid vehicles (series, parallel, or fuel cell)
- Distributed freely to public on NREL's web site

ADVISOR's User Growth Has Exceeded Expectations (over 6,000 people)

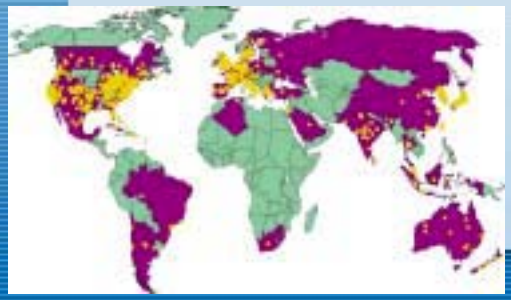


2/3 of Users are from Industry, Major Auto OEMs, and Suppliers





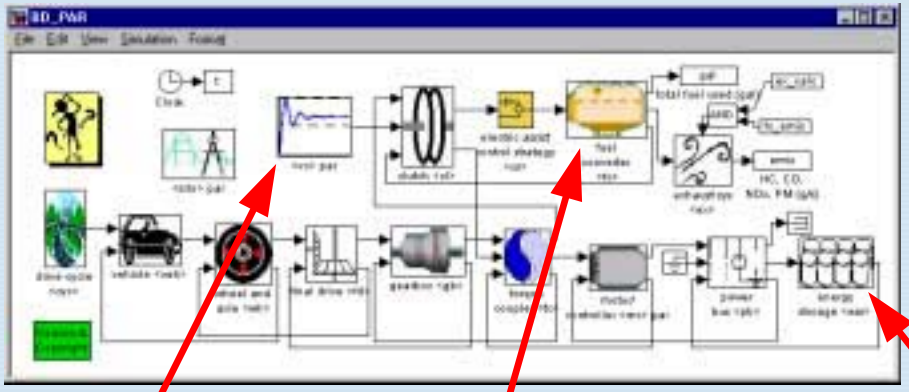
- Ford Motor Company
- Visteon
- DaimlerChrysler Corporation
- General Motors
- Delphi
- Volvo
- Siemens Automotive Systems
- Ricardo, Inc.
- Hyundai Motor Company
- Honda
- Hitachi Ltd.
- Fiat
- Eaton Corporation
- Nissan Motor Company
- Mathworks
- FEV Engine Technology
- Renault
- Mitsubishi Motors Corporation
- Flowmaster
- AVL
- Denso Corporation
- Allison Transmission



Legend includes organizations with 8 or more users since v2.0

As of 9/20/02

ADVISOR's Basic Structure (models) in Matlab/Simulink Environment

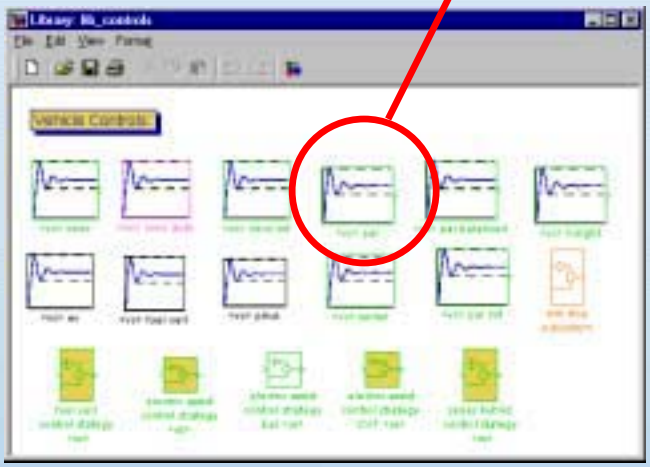


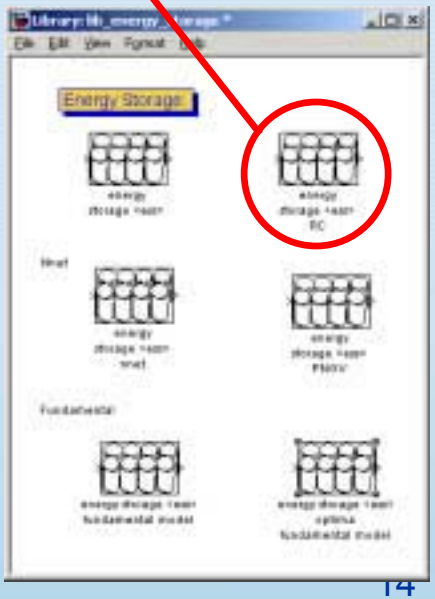
Block Diagram

Battery

Control

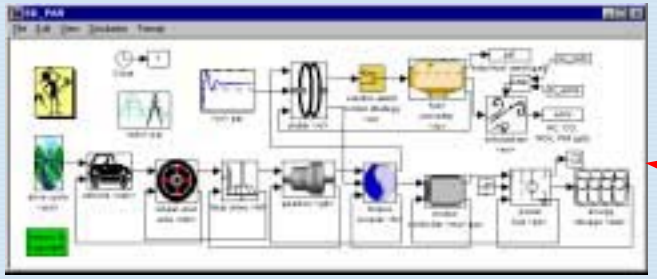
Engine





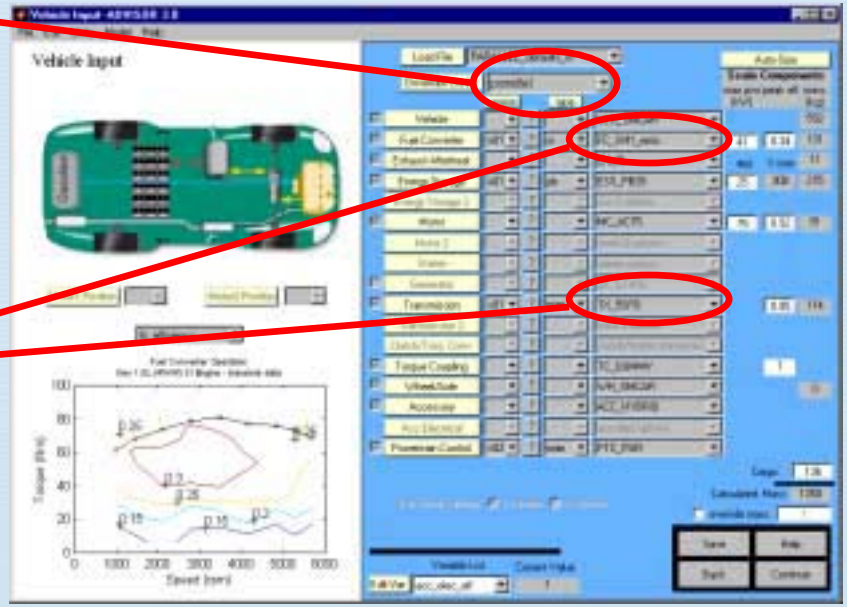
Libraries

ADVISOR's Basic Structure (database): How Data/Models are Pulled into the GUI



Block Diagram

GUI

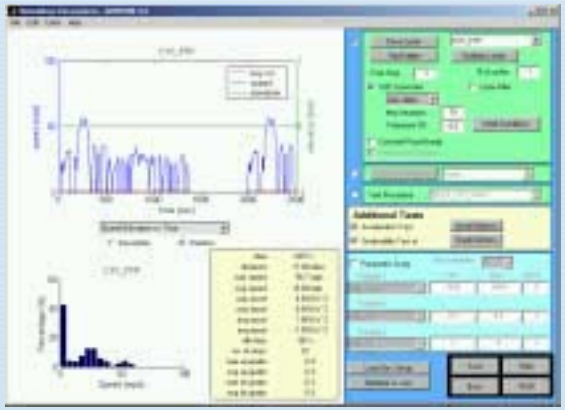


Data Files

Three Main ADVISOR GUI Screens

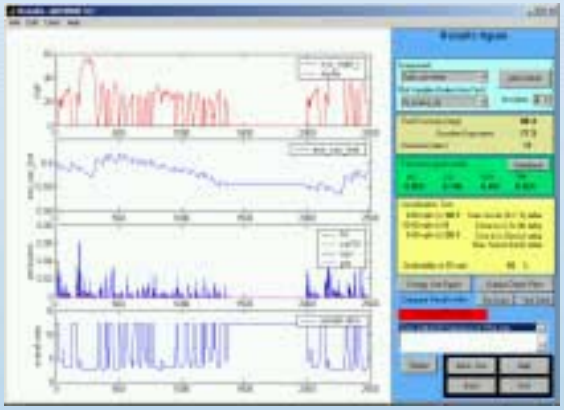
Vehicle Input

Simulation Setup



ADVISOR 2002
Advanced Vehicle Simulator

Results



Demonstration of ADVISOR 2002

What Does Industry Have to Say About NREL's Systems Analysis Team and ADVISOR?

DAIMLERCHRYSLER

"These are very powerful tools and essential in the development of our hybrid vehicles at DaimlerChrysler."

Min Sway-Tin, Supervisor HEV Electrical Engineering
HEV Platform Engineering
DaimlerChrysler Corp.

Allison Transmission

[redacted]

"ADVISOR has been invaluable in Delphi's development of codes to predict the performance of stop/start and integrated starter generator vehicles."

John MacBain
Staff Research Engineer
Delphi Automotive Systems

ENOVA SYSTEMS

Ford Motor Company

"… We have found this collaboration to be very helpful since the NREL team brings new, fresh, out-of-the-box ideas and high level technical expertise."

Tsung-Yu Pan, Ph.D.
Senior Technical Specialist, Manufacturing Systems
Ford Research Laboratory

Visteon

Simulation Controls

Time: 354.0

Car Graphics On/Off

Vehicle Controls and Display

RPM X 1000

Engine On:

0.00 MPH

Inst. Trace Miss:

Trip Trace Miss:

FUEL USED (gal): 0.119 0.000

FUEL FLOW (g/s): 1.754 0.000

53

40

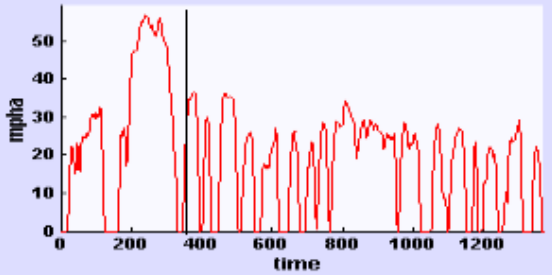
parallel_hybrid.mat

series_hybrid.mat

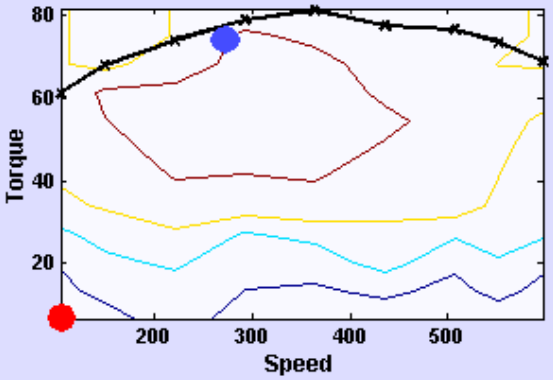
Simulation Outputs

Close

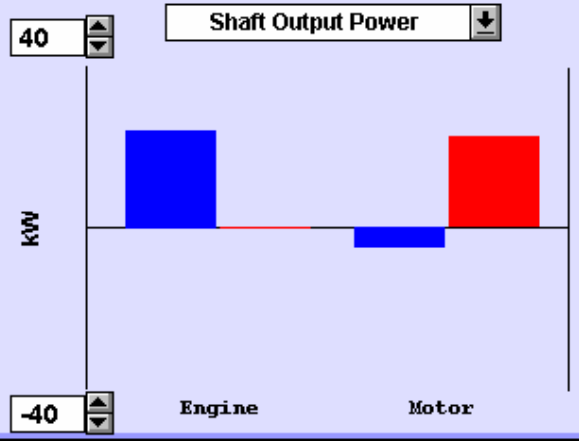
Speed/Time Profile



Fuel Converter Efficiency

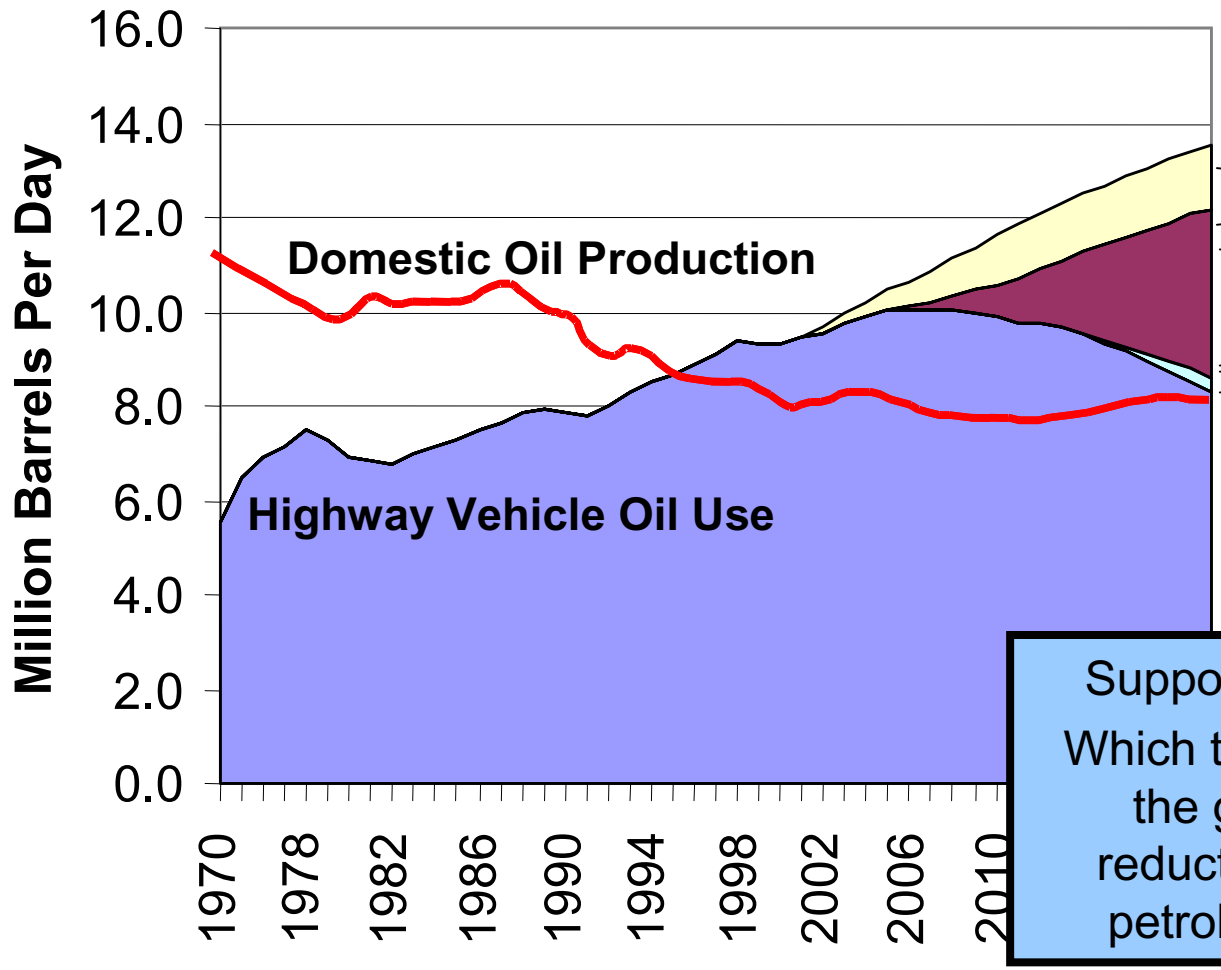


Shaft Output Power



Technical Targets Tool Motivation:

Produce National Impacts Due to Potential Changes in Technical Targets



Alternative fuels -10% of total vehicle population

42 mpg combined cars & trucks

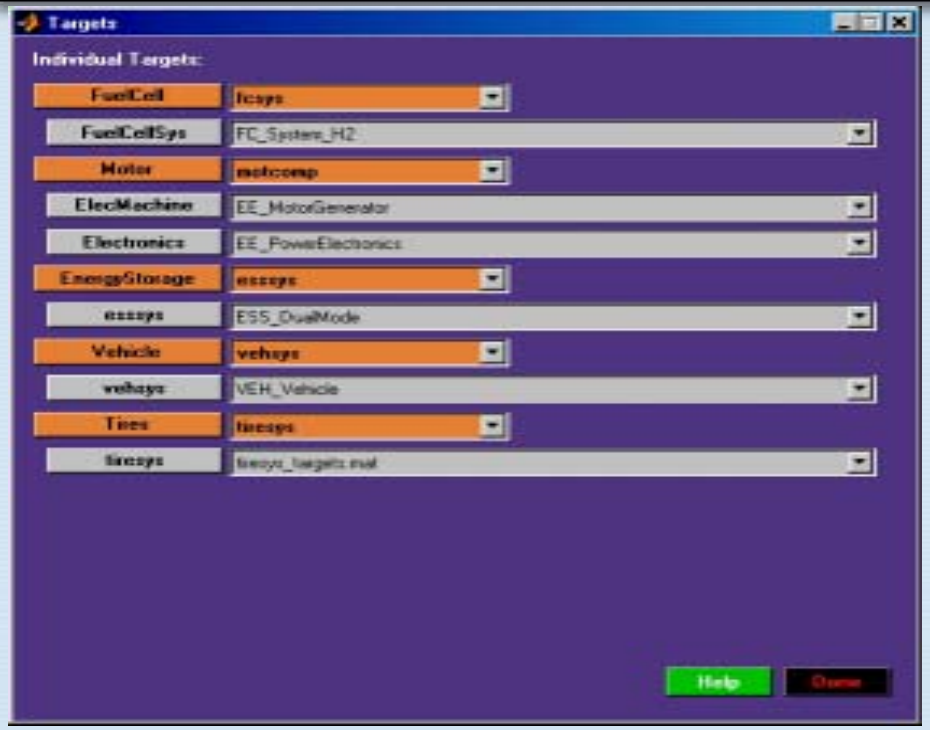
Fuel cell vehicles - 10% of new sales by 2020

Supports the "**Big Picture**"

Which technologies will have the greatest impact on reduction/displacement of petroleum consumption?

Source: Tom Gross presentation at Clean Cities Day 3/12/02

Objectives of Technical Targets Tool



- Provide a tool to assess/compare impact of various tech team targets
- Allow changes tech team target values, and have ADVISOR define vehicles and estimate fuel efficiency
- Consider the ability of the new technology vehicle to penetrate a multi-platform market
- Figure of Merit: **national oil savings**

Technical Targets Tool Approach

User

Technology Assessment

Goal: Meet tech targets and market requirements for each platform

ADVISOR inside

Result: Segment Y/N, mpg

Market Characterization

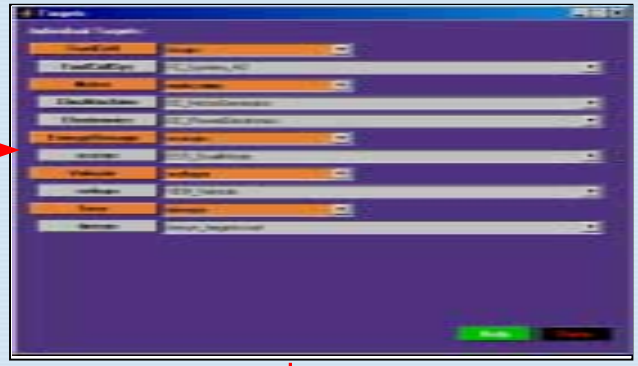
- Segment market into vehicle platforms
- Define segment/vehicle requirements, mpg

National Oil Use

Project market penetration and resultant oil use

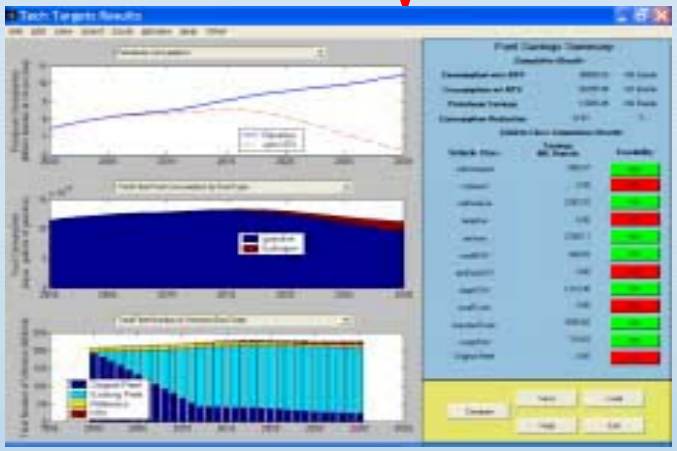
Technical Targets Tool Flow

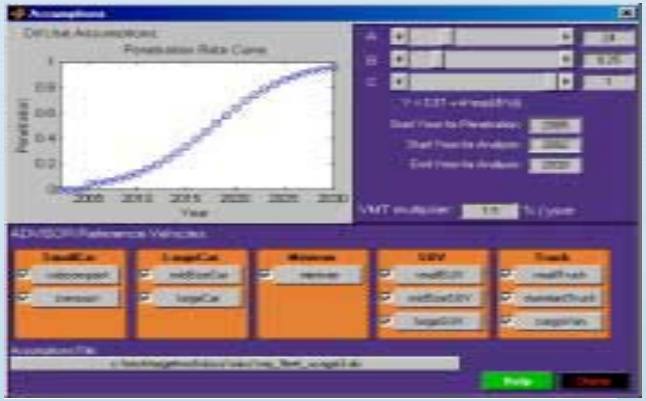
Target Values



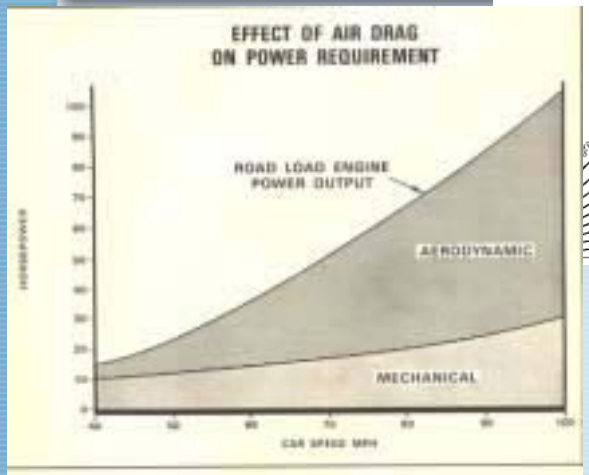
Model Parameters

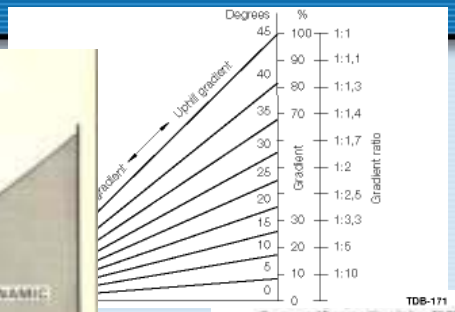
NTV CPIs/MPGs

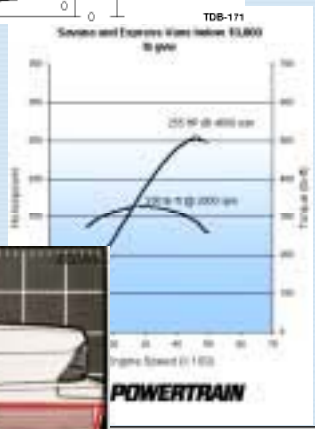


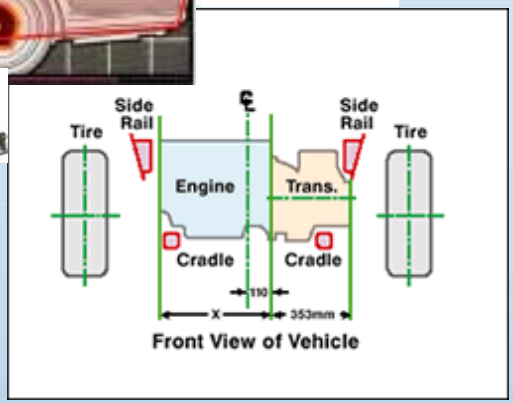


Reference Vehicle Attributes



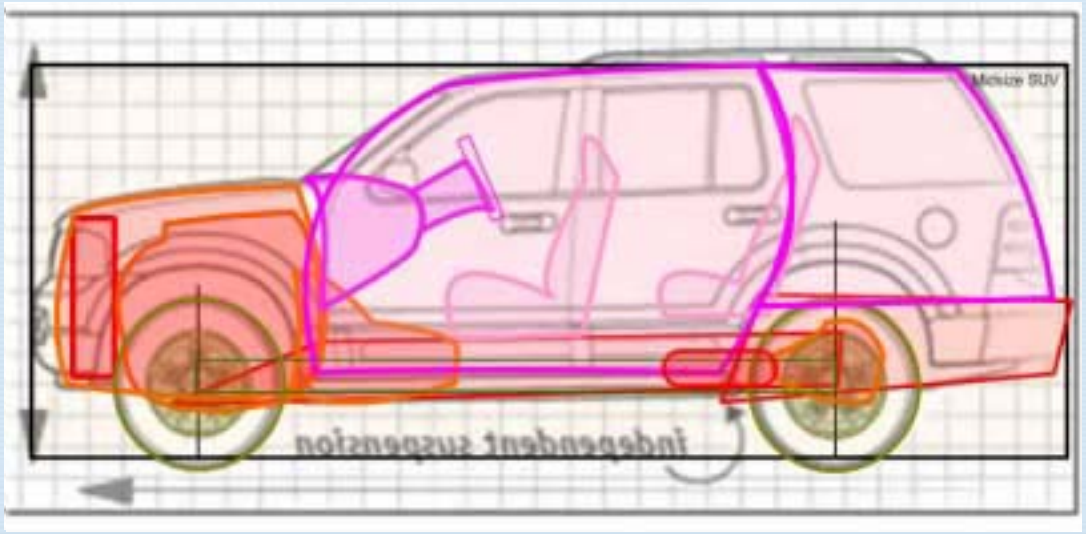






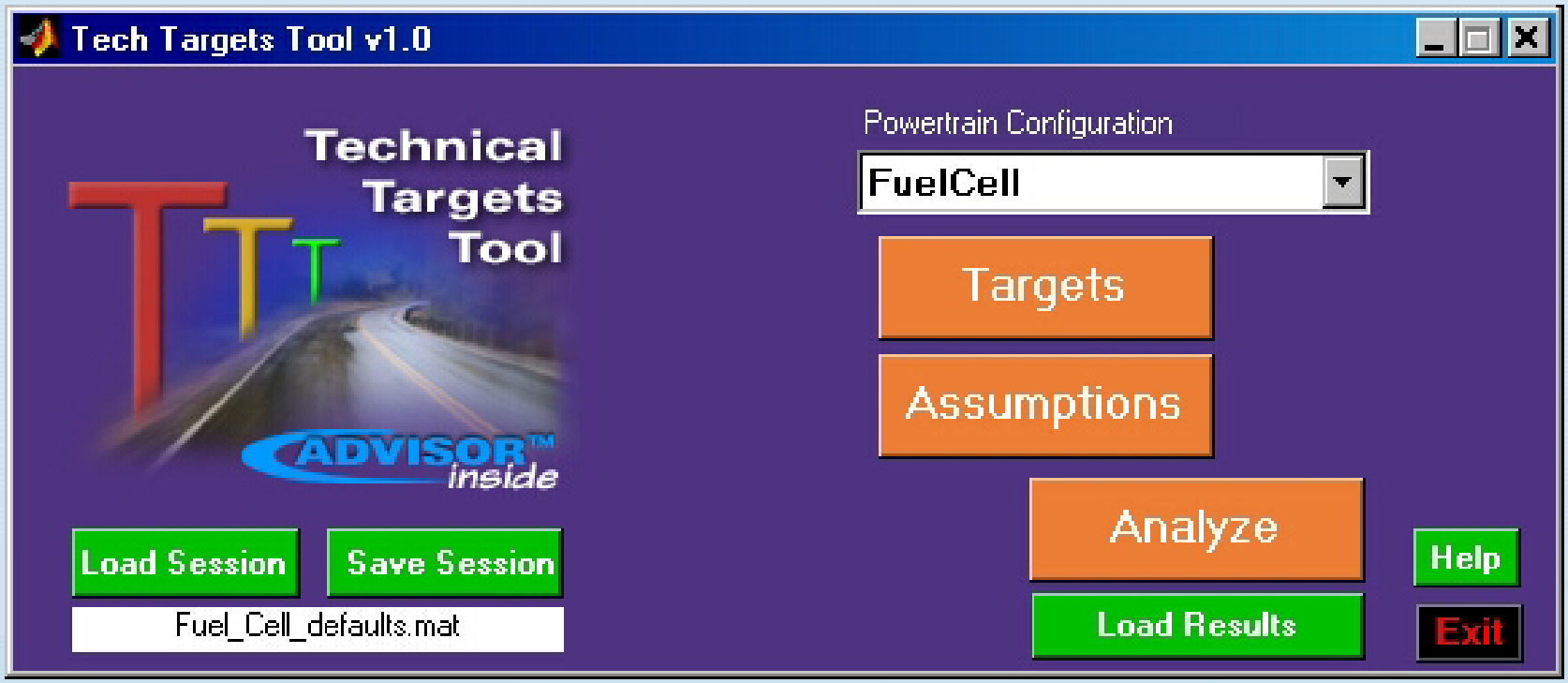
- Physical
  - Curb mass, glider mass, C_D, A_f, wheelbase, tires
  - Available space for new powertrain
- Fuel Converter - Transmission
  - Max power and torque, transmission type
- Performance
  - Acceleration
  - Gradeability
  - Fuel economy
  - Range

Available Propulsion Package Volume

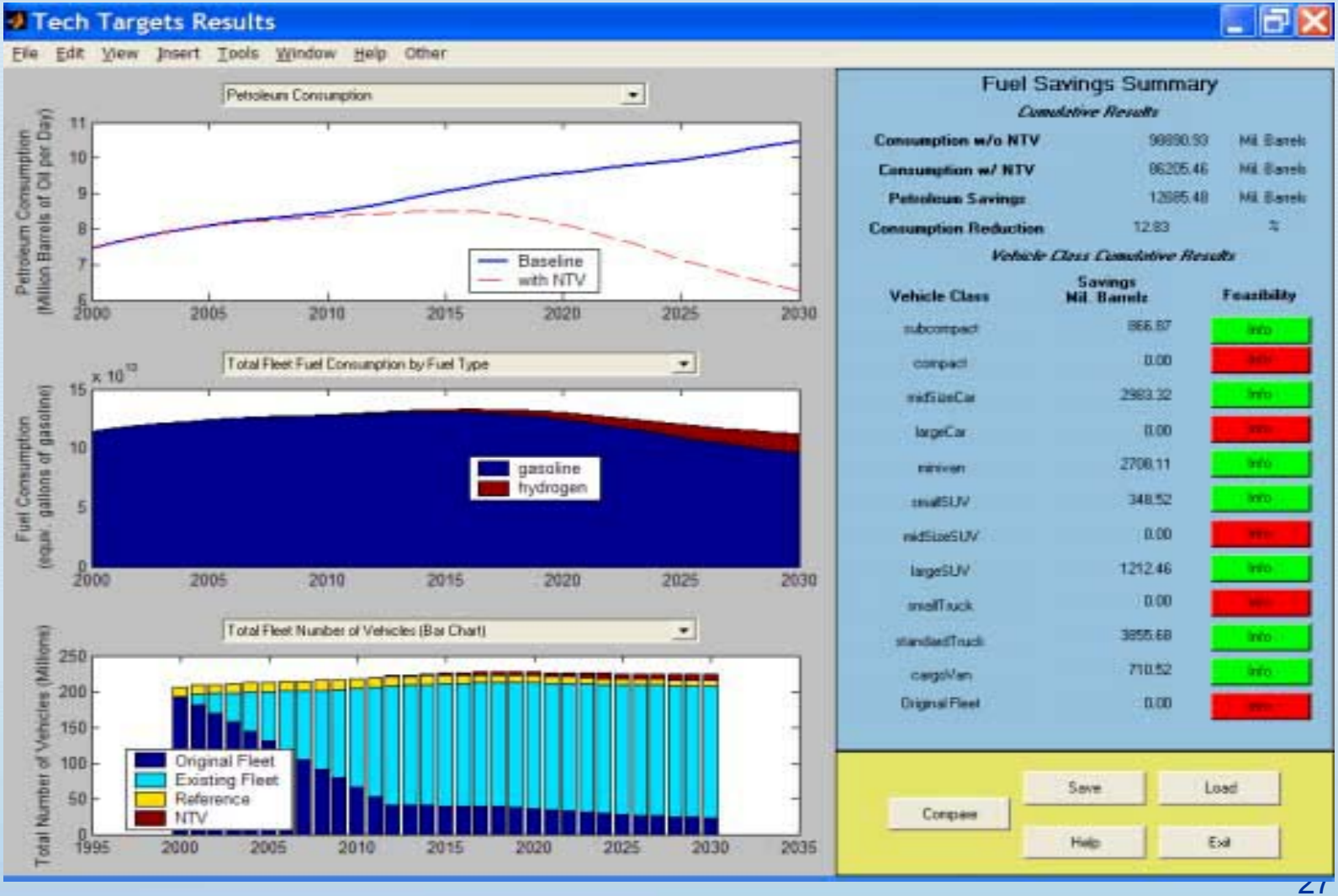


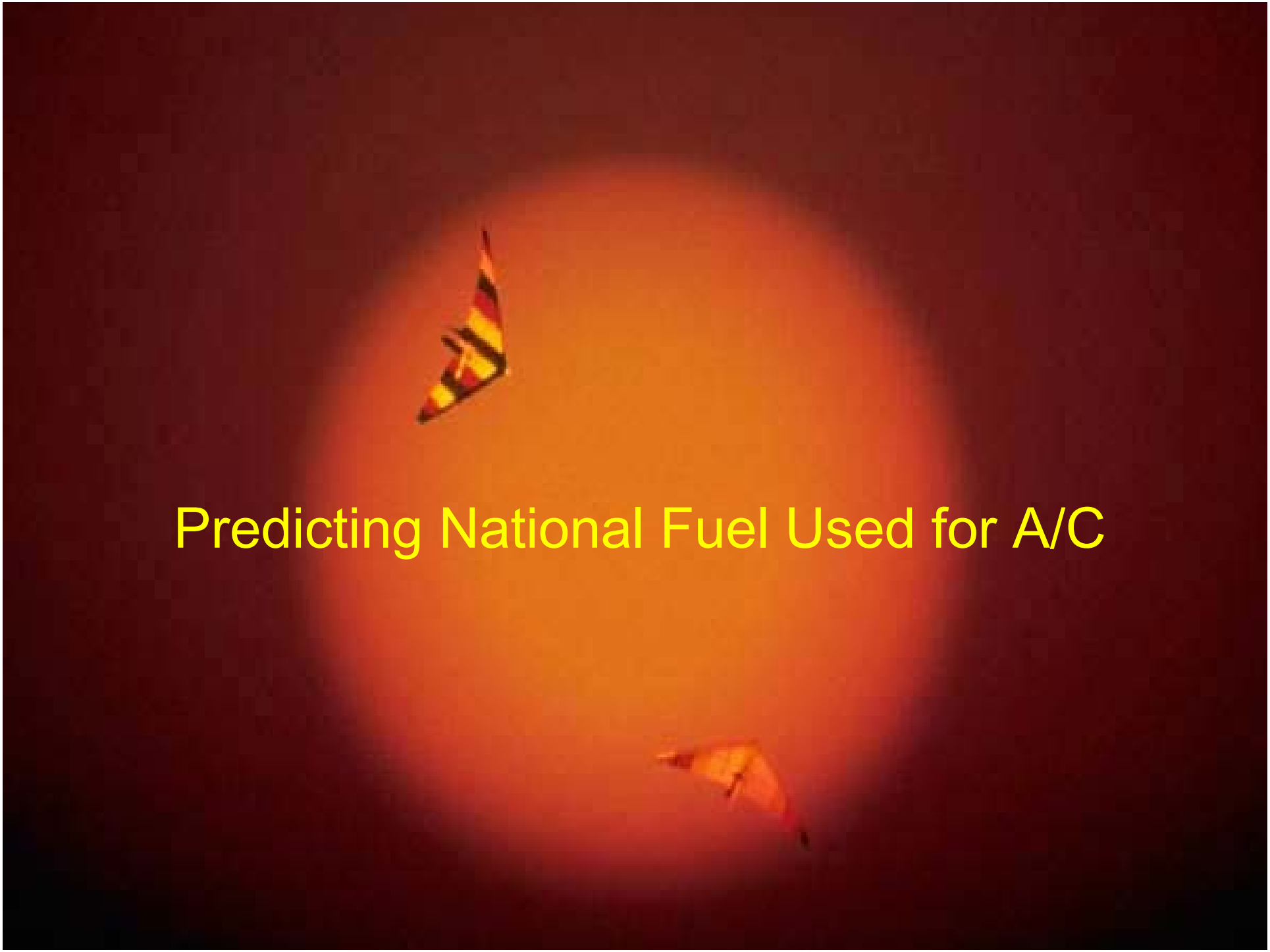
- Vehicle Classified Pass & Cargo Volume Index
- Change out of Index Range is Change in Class
- Finite Propulsion Space Available within Vehicle
- New Technology must Package

T³ Demonstration



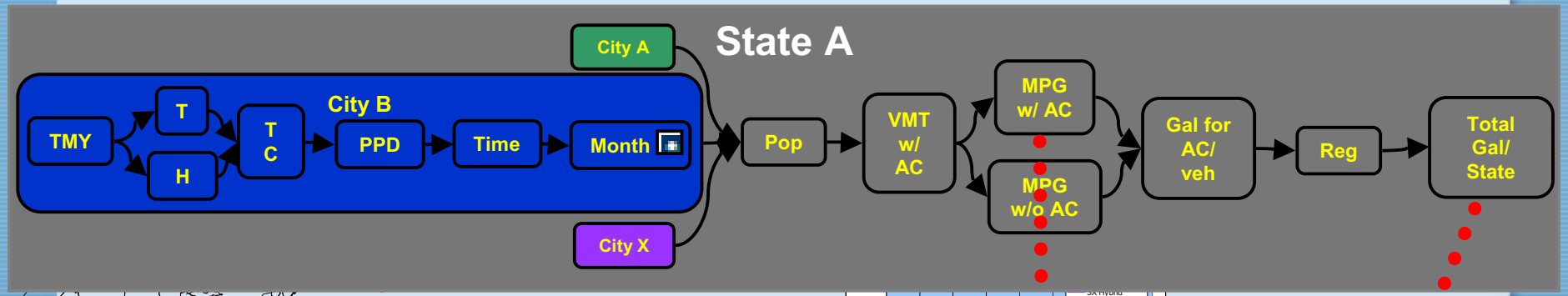
Example of Results Screen

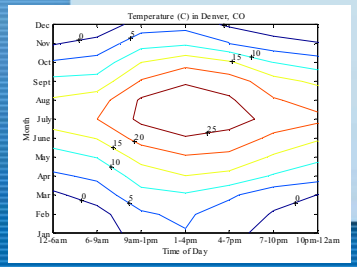


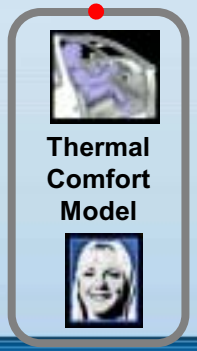

Predicting National Fuel Used for A/C

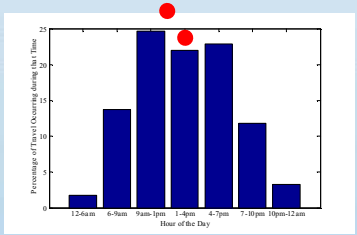
Predicting National Fuel Used for AC

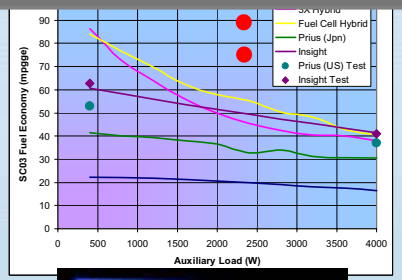
- Use Multiple Models/Inputs/Data Sets
  - Environmental Conditions (Temp, RH, W/m^2)
  - Thermal Comfort Models
  - Vehicle Simulations (Fuel Economy Reduction with AC)

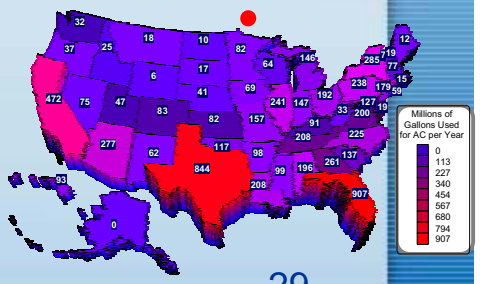




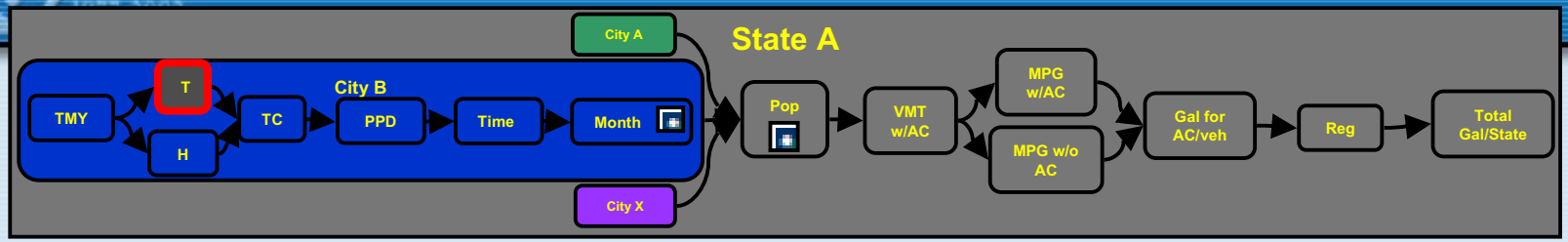




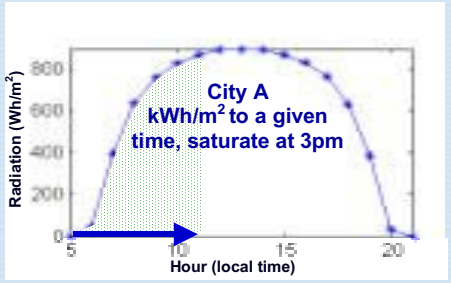


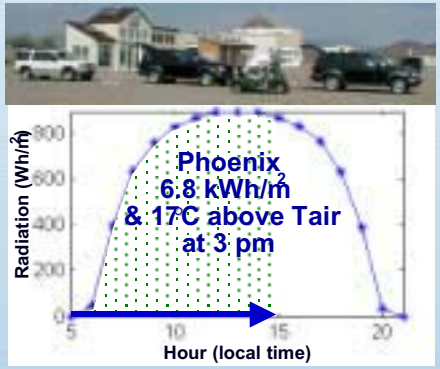


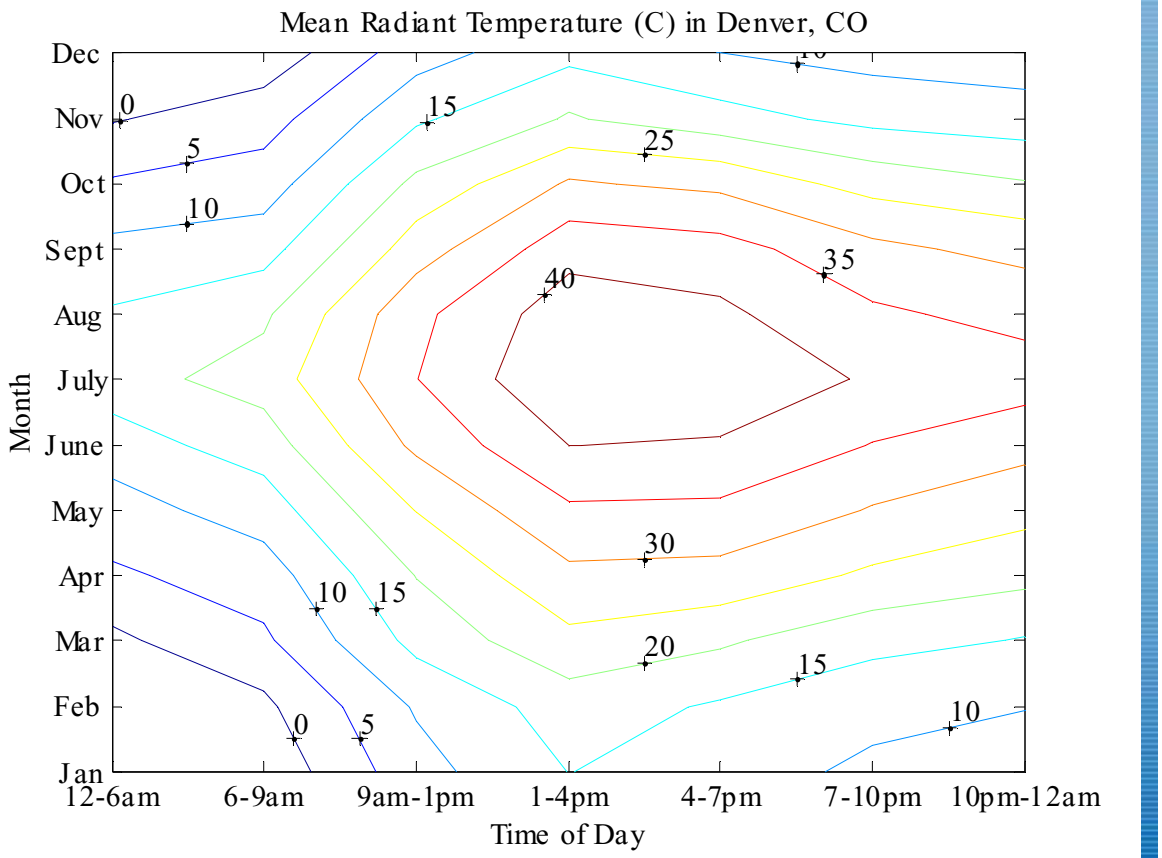
Environmental Conditions: Denver, CO, Mean Radiant Temperature



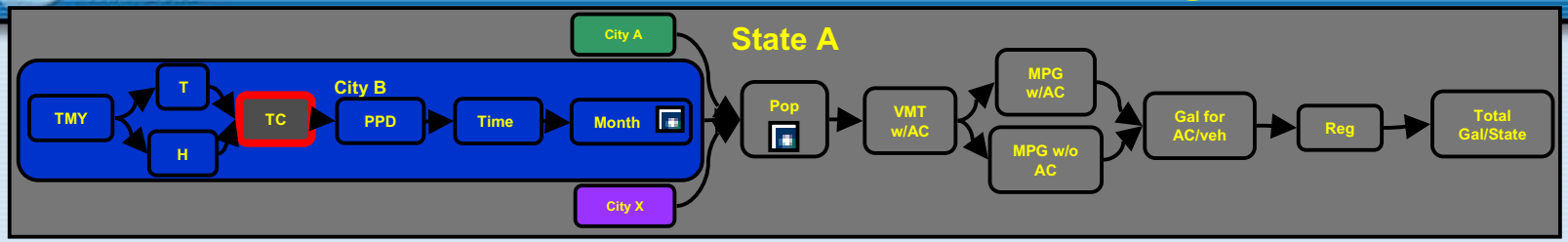
- Source: Typical Meteorological Year, National Solar Radiation Data Base





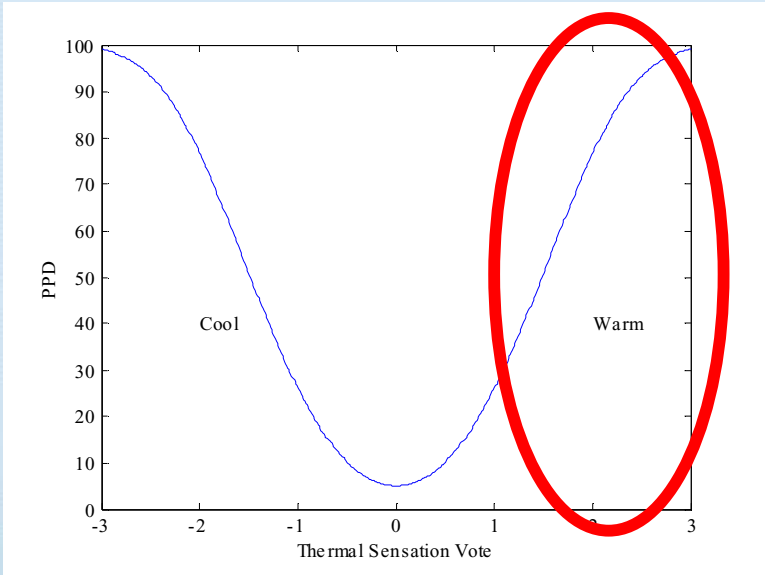


Thermal Comfort Model: Percent of People Using AC



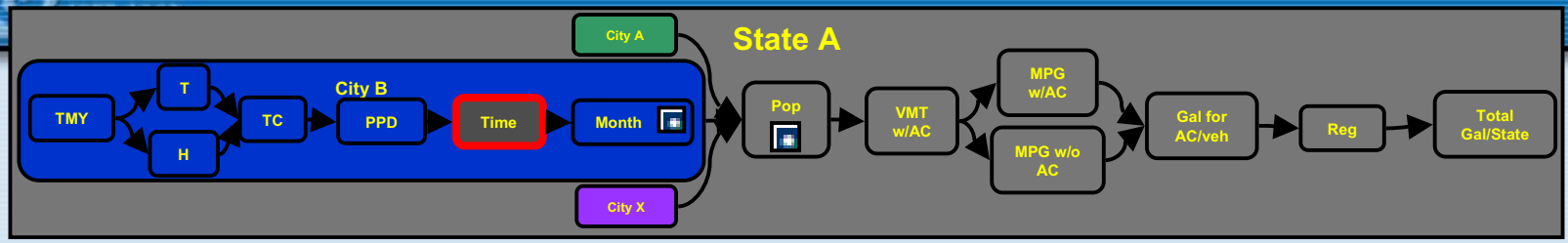
Thermal Comfort Model, *PPD from PMV*

PMV	Thermal Sensation
+ 3	Hot
+ 2	Warm
+ 1	Slightly Warm
0	Neutral
- 1	Slightly Cool
- 2	Cool
- 3	Cold



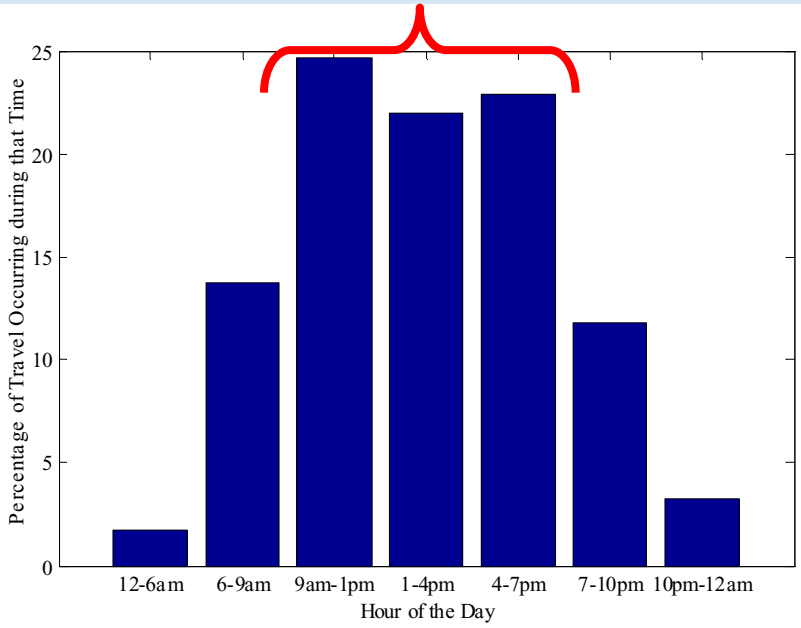
- Source: International Standards Organization (ISO) 7730 "Moderate thermal environments—Determination of the PMV and PPD indices and specification of the conditions for thermal comfort"

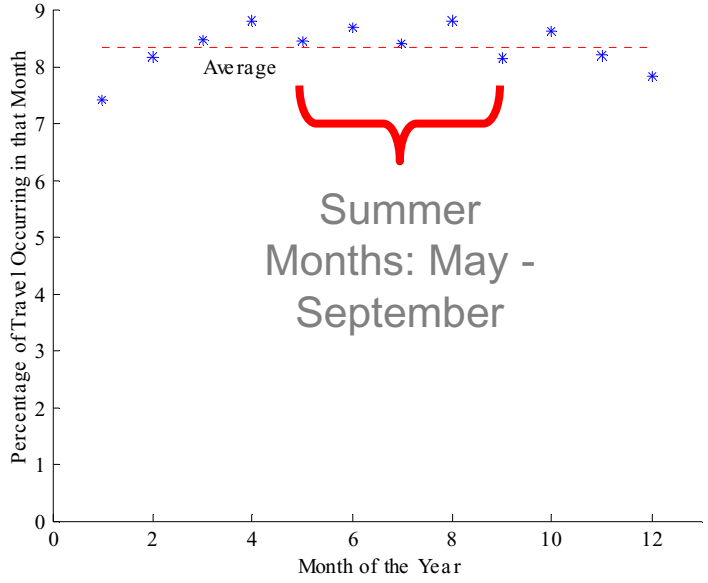
Vehicle Usage with Time of Day, Month



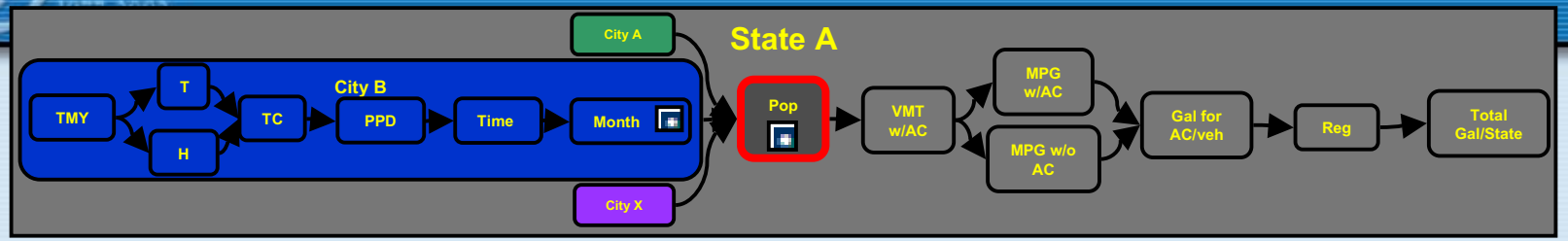
- Source: 1995 National Personal Transportation Survey

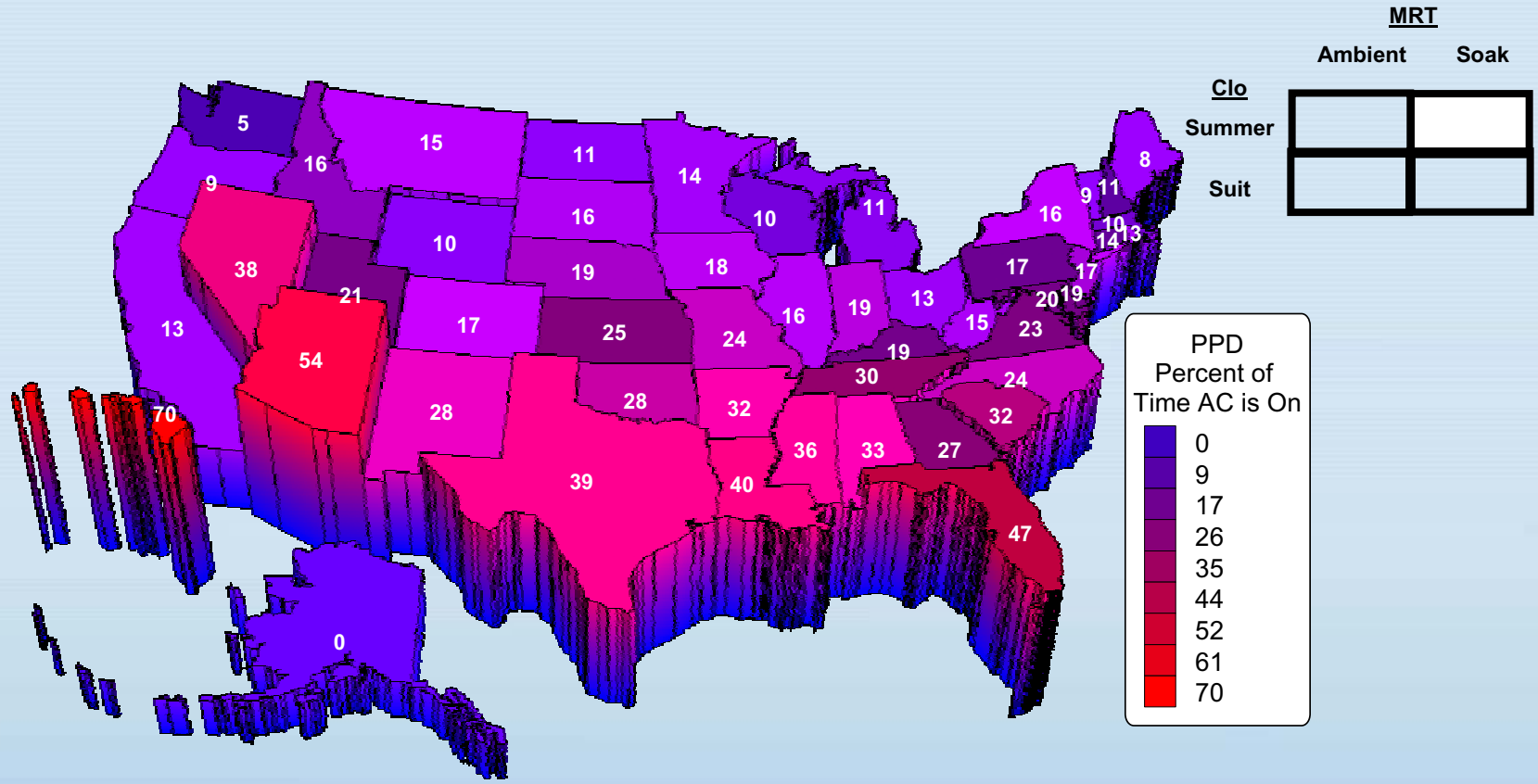
70% Daily Travel



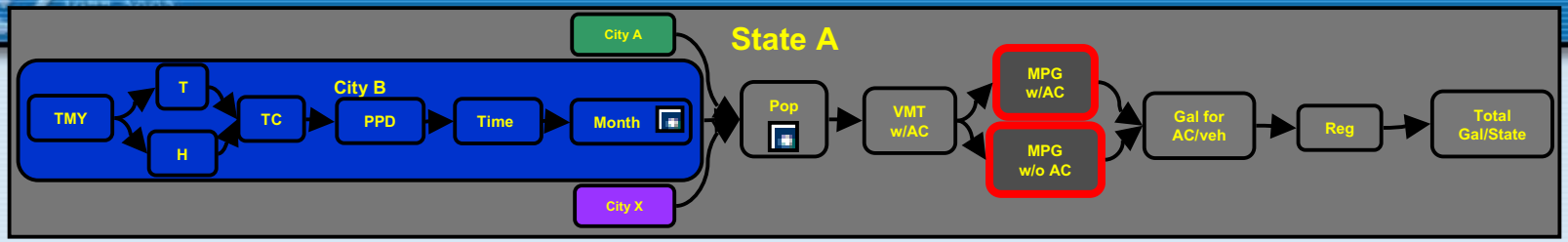


Percent of Time AC is On

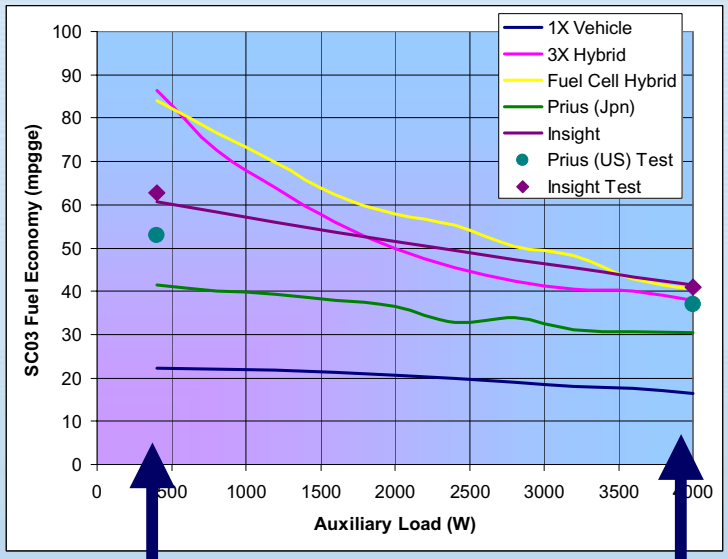




Fuel Economy Impact: Vehicle Simulations



- Source: Wards 2001 Automotive Yearbook
- ADVISOR Simulations for fuel economies



AC Off

AC On

Drop in Fuel Economy 400-4000 W

3X: 56%

FC: 52%

Insight: 32%

Prius: 27%

1X: 26%

ADVISOR FTP Fuel Economy at 3000 W

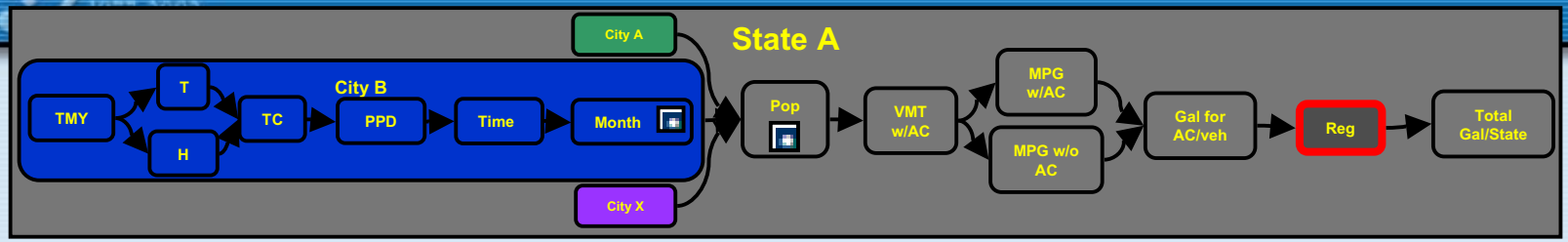
Cars

22 to 16.7 mpg: 24%

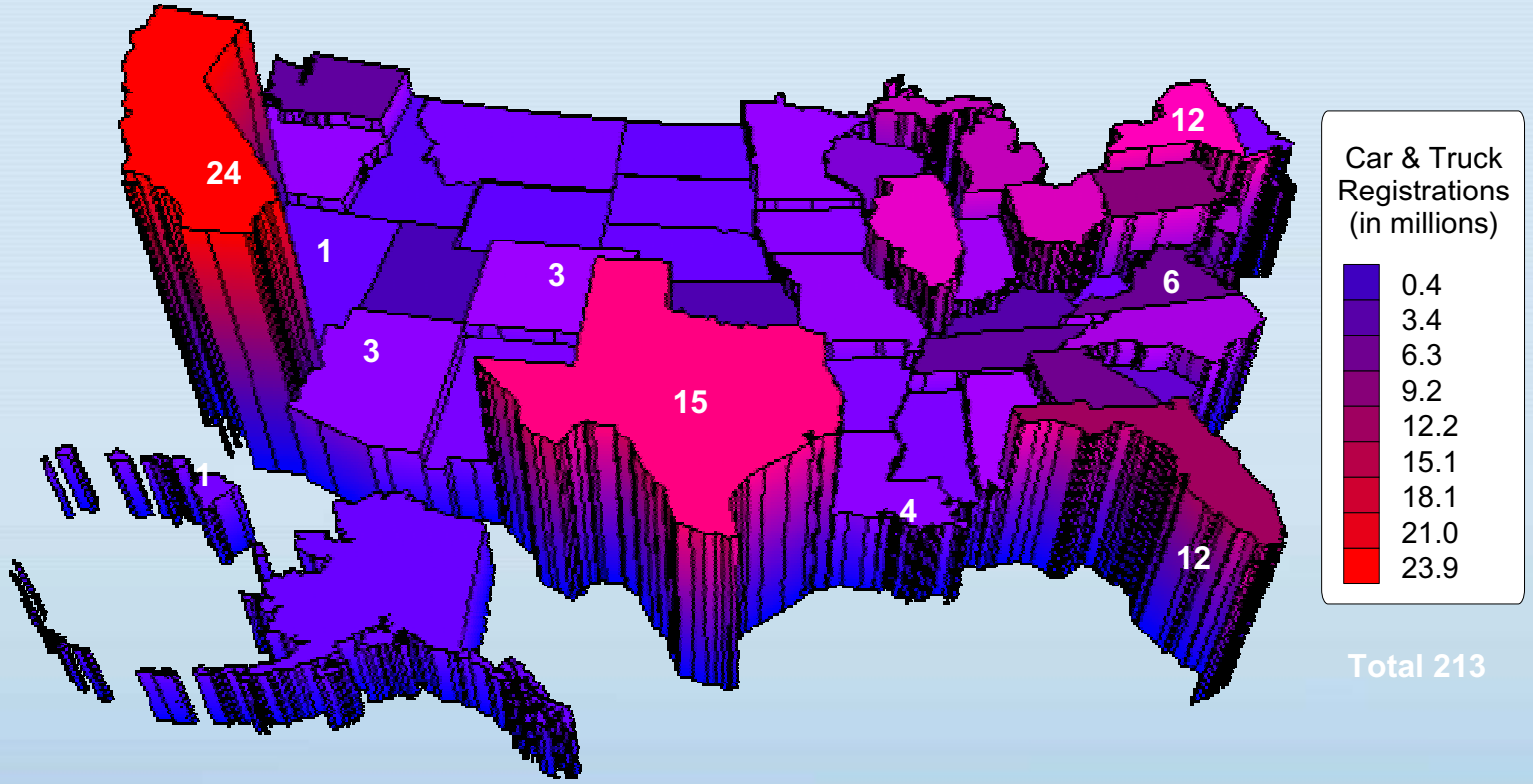
Trucks

17.7 to 14.9 mpg: 16%

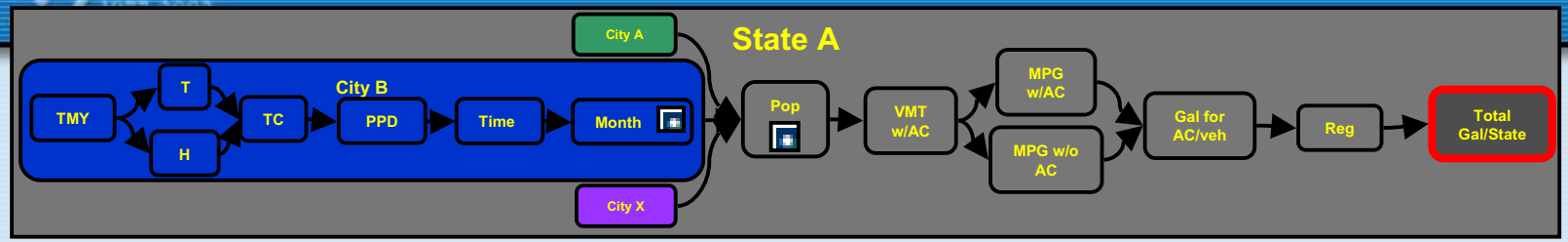
Vehicle Registrations



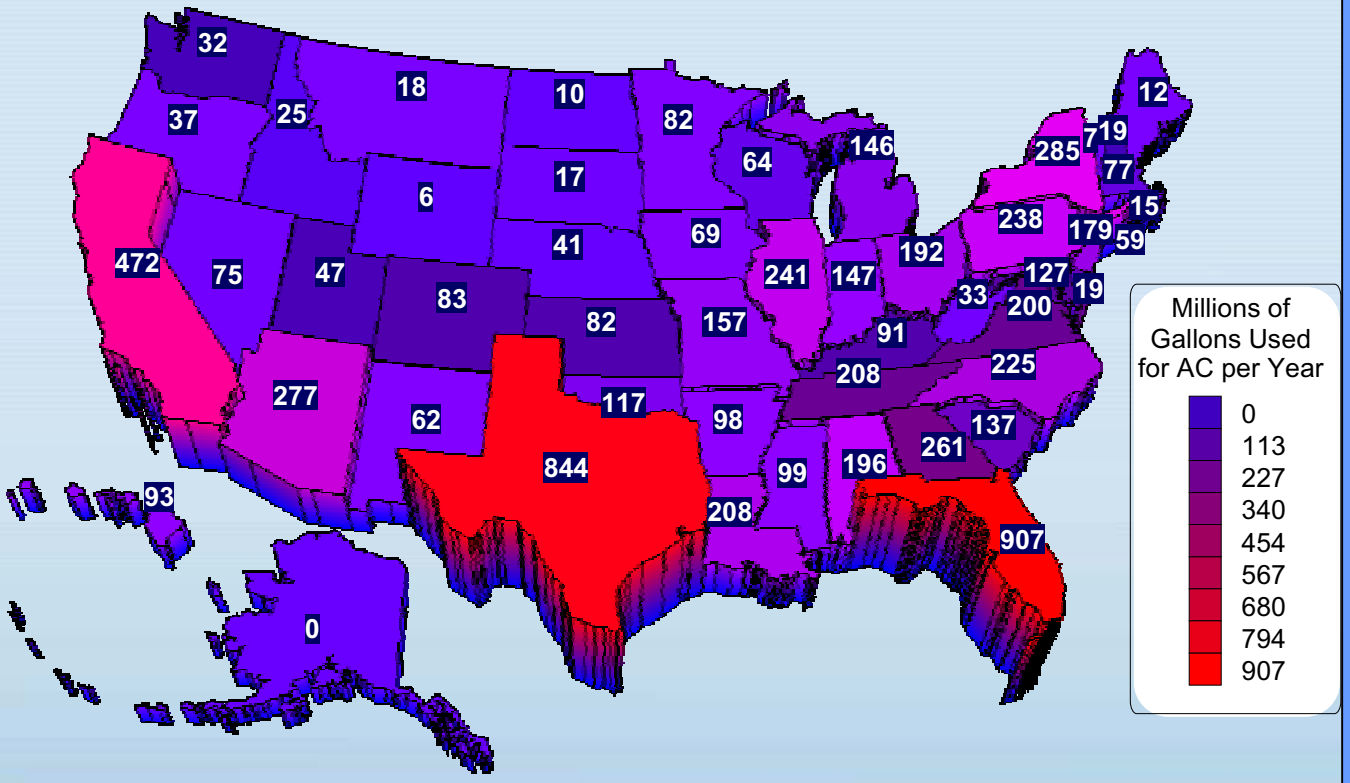
- Source: Wards 2001 Automotive Yearbook



National Fuel Used for AC



- 7.1 billion gallons used for air conditioning annually



MRT

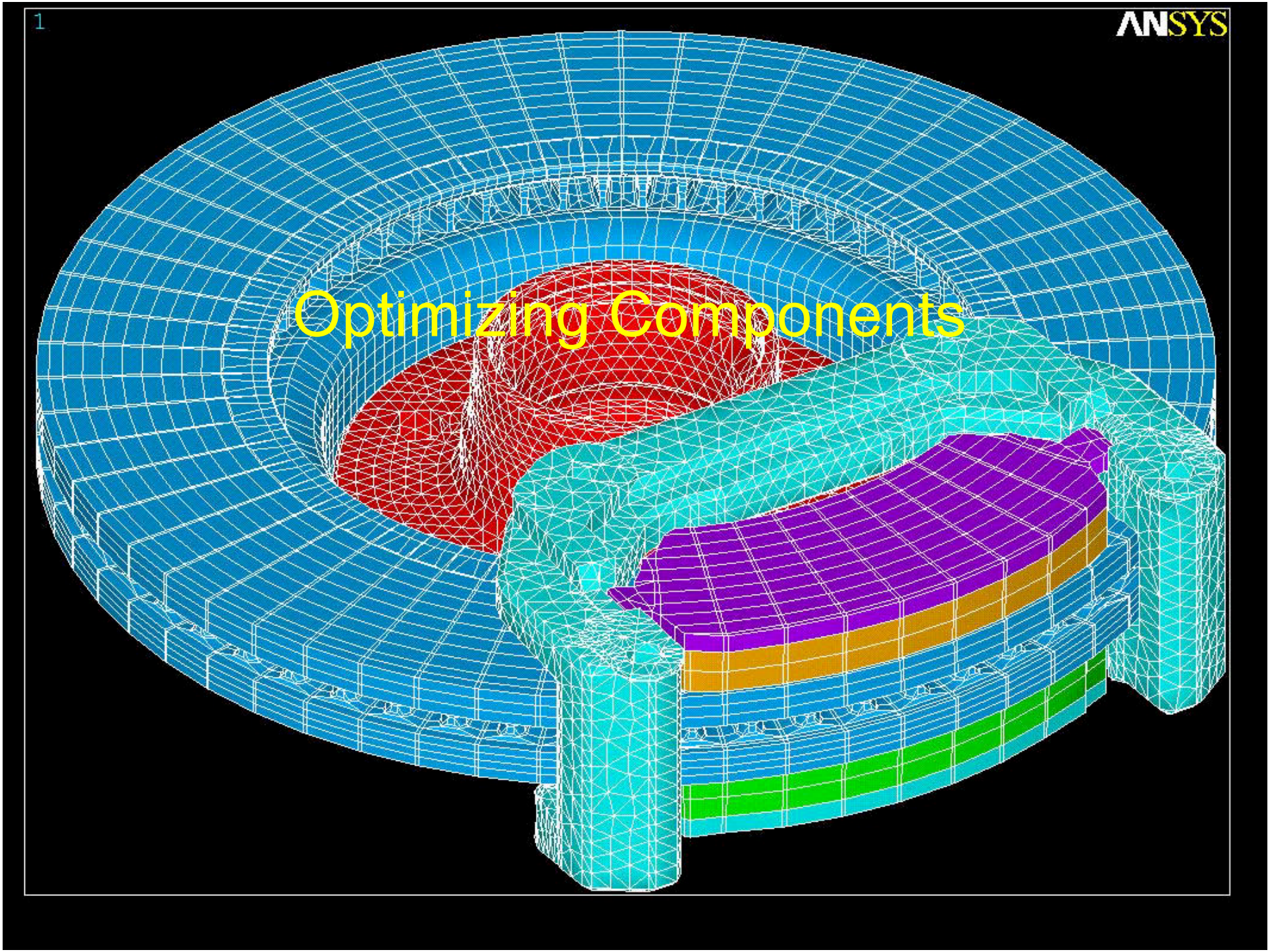
Clo	Ambient	Soak
Summer	2.6	7.1
Suit	4.7	9.2

Fuel Used for AC, in Billions of Gallons

MRT

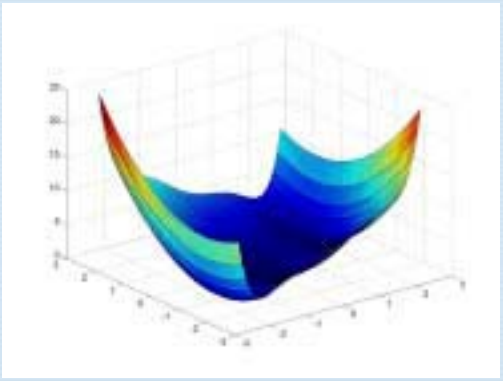
Clo	Ambient	Soak
Summer	3.5	10
Suit	6	13

Fuel Used for AC, Percent of Total US Crude Oil Imports

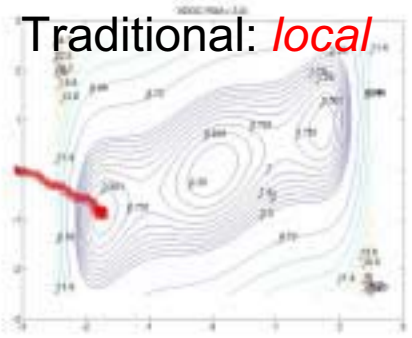

1
ANSYS
Optimizing Components

Example of Applying Optimization Techniques *Fuel Cell Hybrid SUV*

- Objective: Maximize fuel economy of Fuel Cell Hybrid SUV
- Optimizing coupled problem of sizing and control strategy leads to improved solution
- Multiple local optimums in HEV design space



Traditional: *local*



Non-traditional: *global*

Using ADVISOR in an Optimization Loop as both the Function Call and Constraint Evaluation

~5-10 drive cycle iterations for SOC balancing

Optimization Tools

ADVISOR

Objective Function $f(x)$

Constraint Function $g(x)$

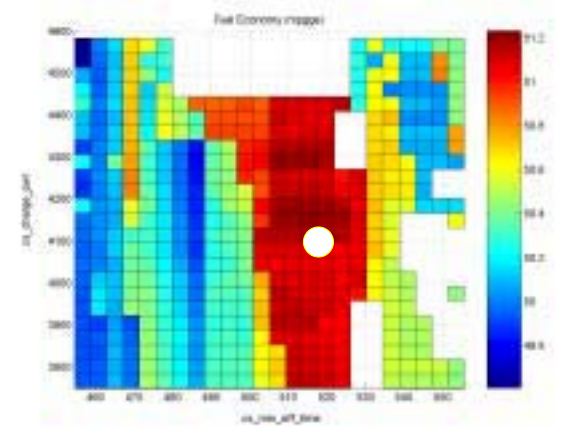
Typical optimization loops this 100-2000 times

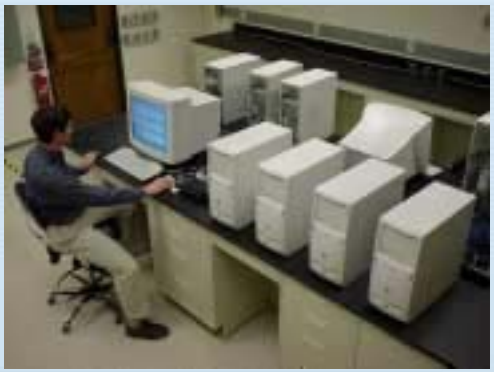
- Acceleration
- Gradeability
- SOC balanced
- Must follow cycle

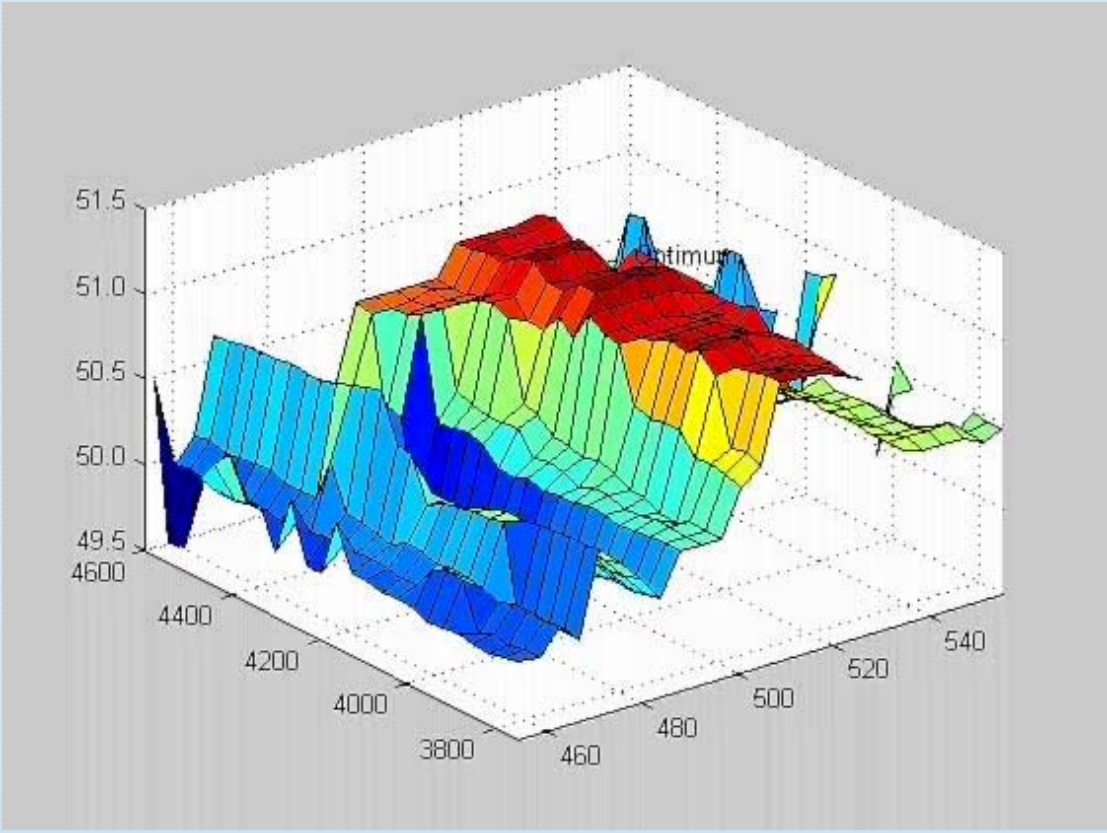
Concept of "ADVISOR Inside" Used With Technical Targets Analysis Tool

Complex Design Space of HEVs

Fuel Economy vs. 2 energy management parameters

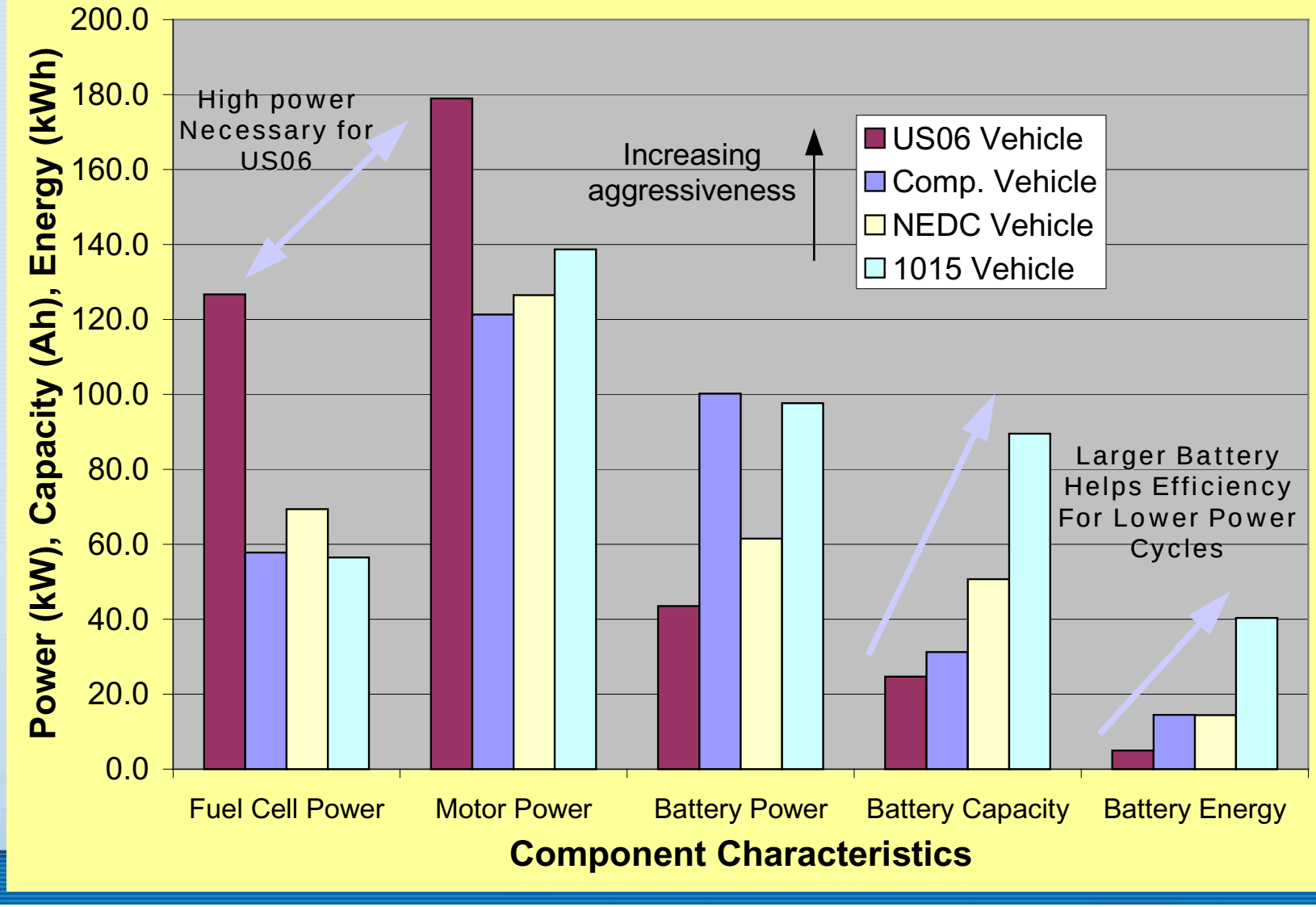






- Note:This only represents small portion (~1/25th) of 2 dimensions of an 8 dimensional space
- We are actually now doing parametric sweeps of these optimization problems (~3000 calls/per point)

Characteristics of Components for Optimized Vehicles

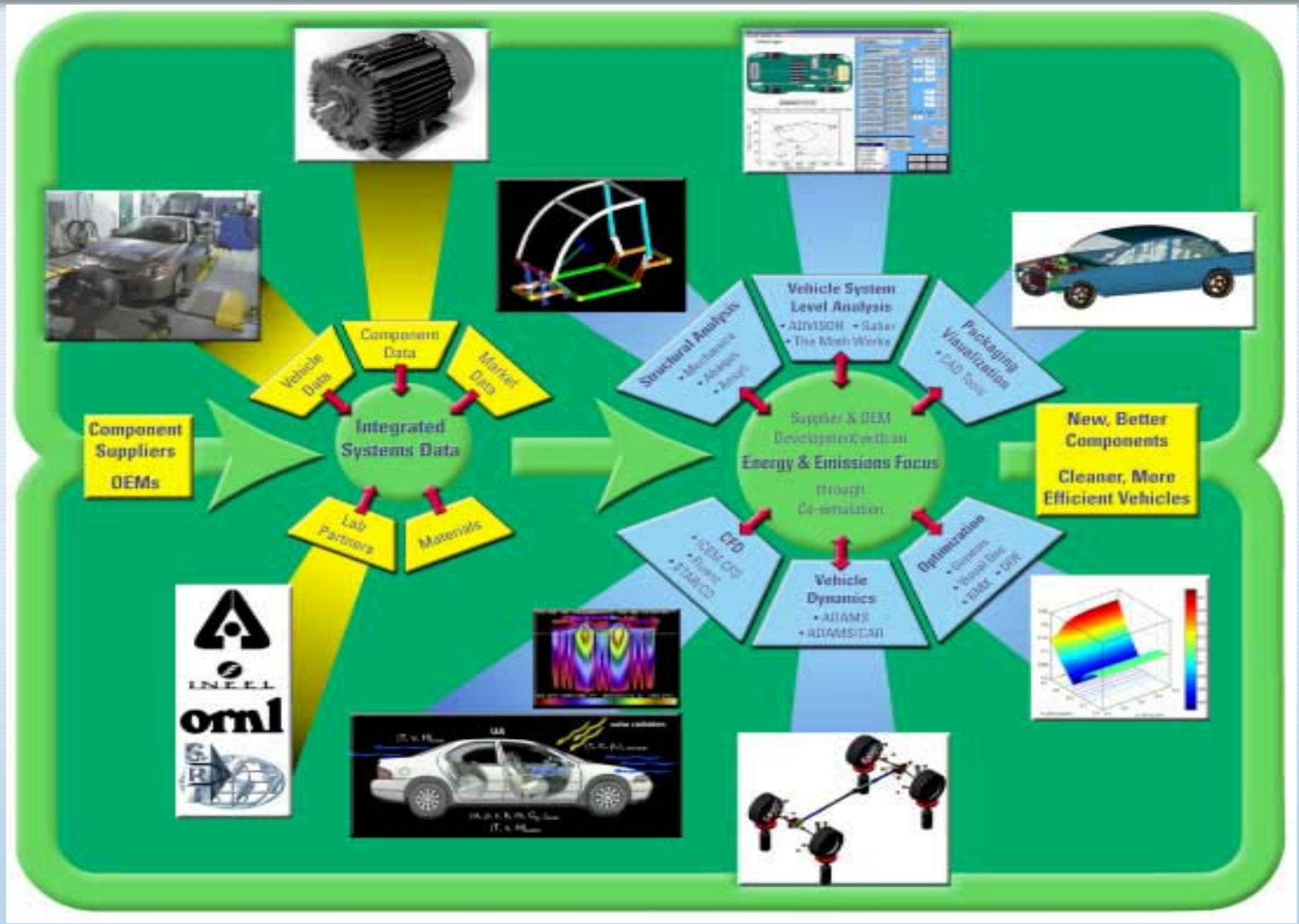


Optimization of Fuel Cell Vehicle Design Provides Insight into System Trade-offs

- Coarse parametric sizing study indicated optimal fuel cell to system power ratio of 0.25-0.3 for fuel economy
- Determined that derivative-free optimization algorithms necessary for complex design space of HEVs
- Drive cycle influences optimal degree of hybridization and control parameters
  - NEDC provides robust design
- Fuel cell transient response capability critical for neat fuel cell vehicle
- An optimized hybrid design can nullify the effects of fuel cell transient response

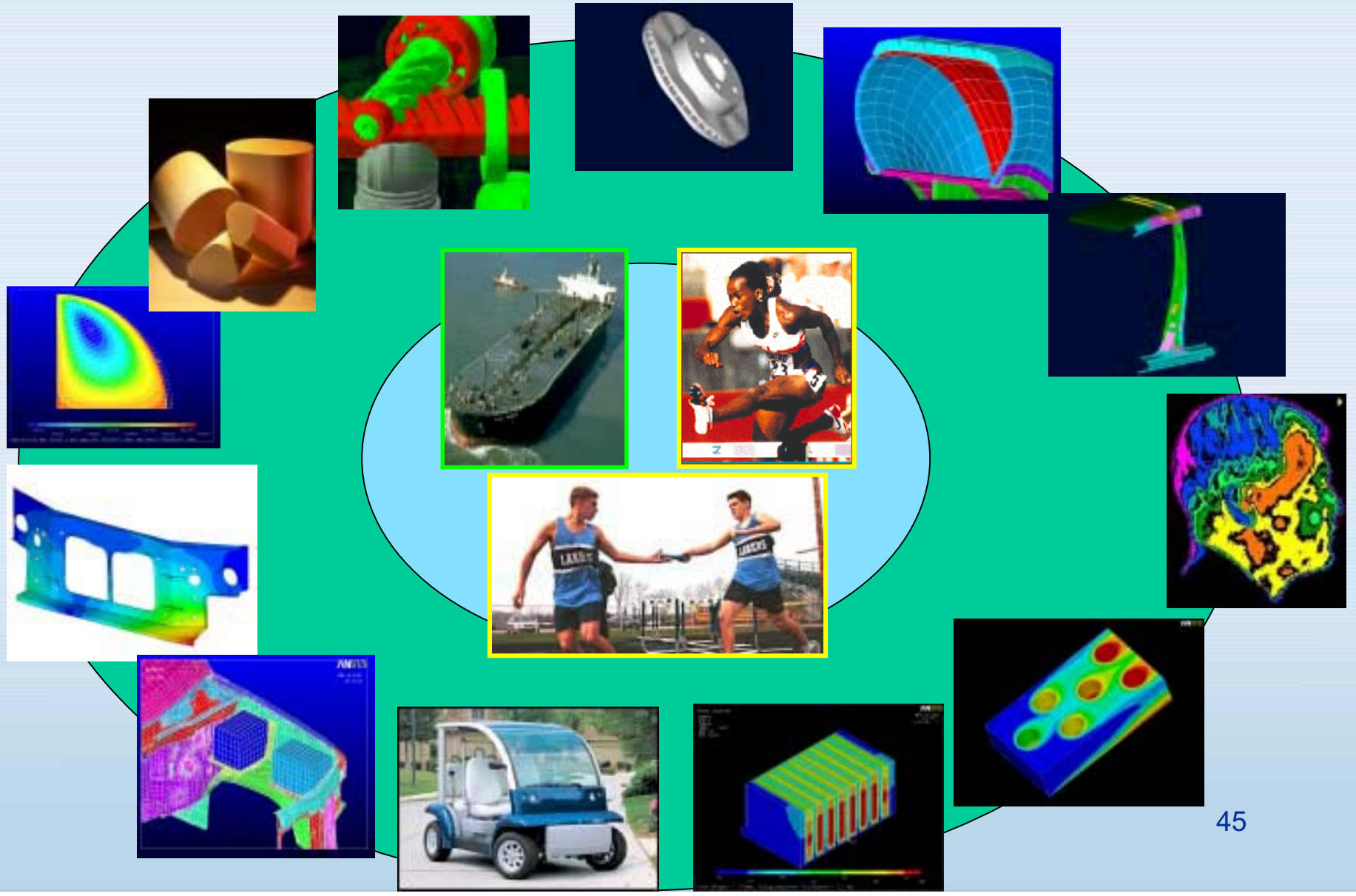
25 Years of Research Excellence 1977-2002

Digital Functional Vehicle



Recent DFV Applications

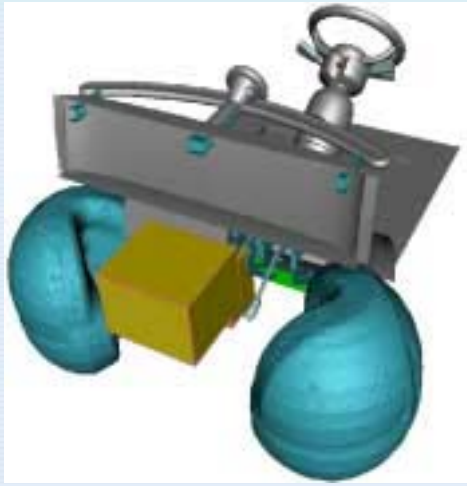
Petroleum Consumption, Technical Hurdles, Transfer to Industry

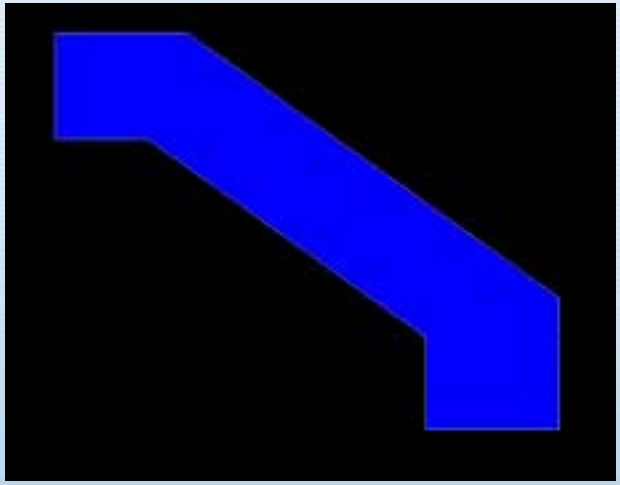


Tools for Optimizing Light-weight Designs with Structural Integrity

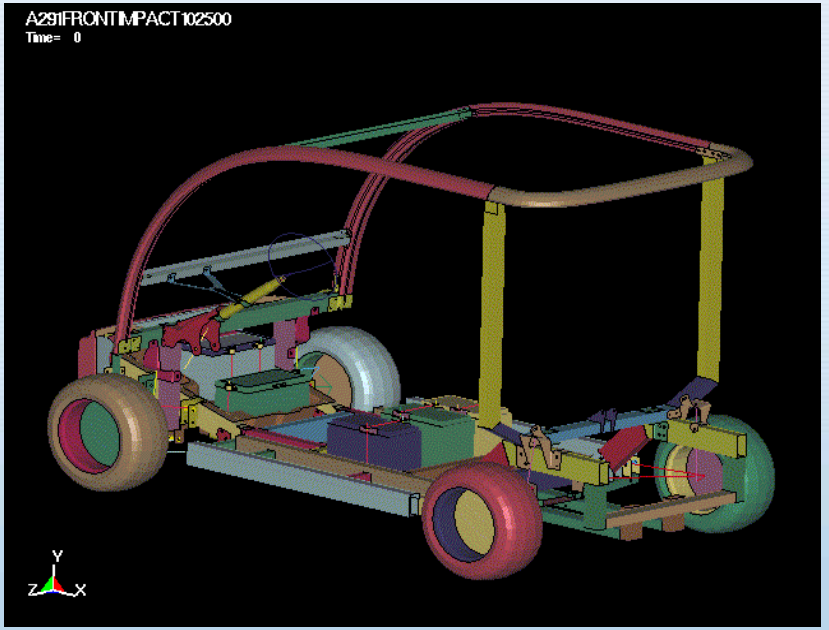
Time to Market

Space
Envelope
Optimization



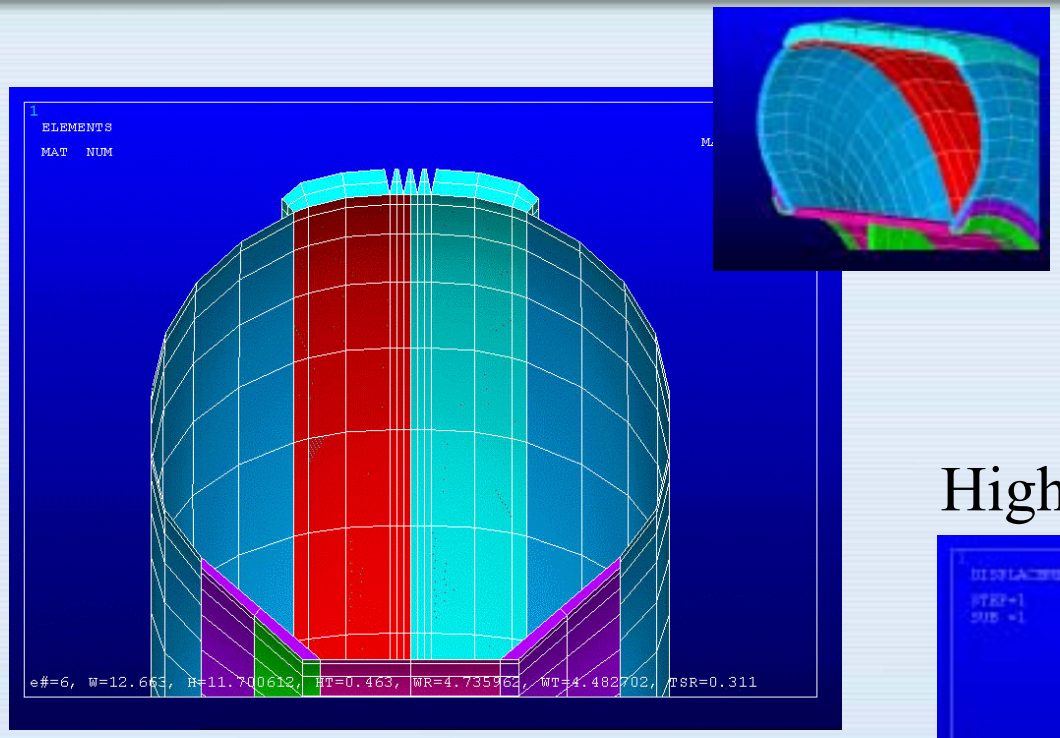


Topology Optimization



Crash Simulation

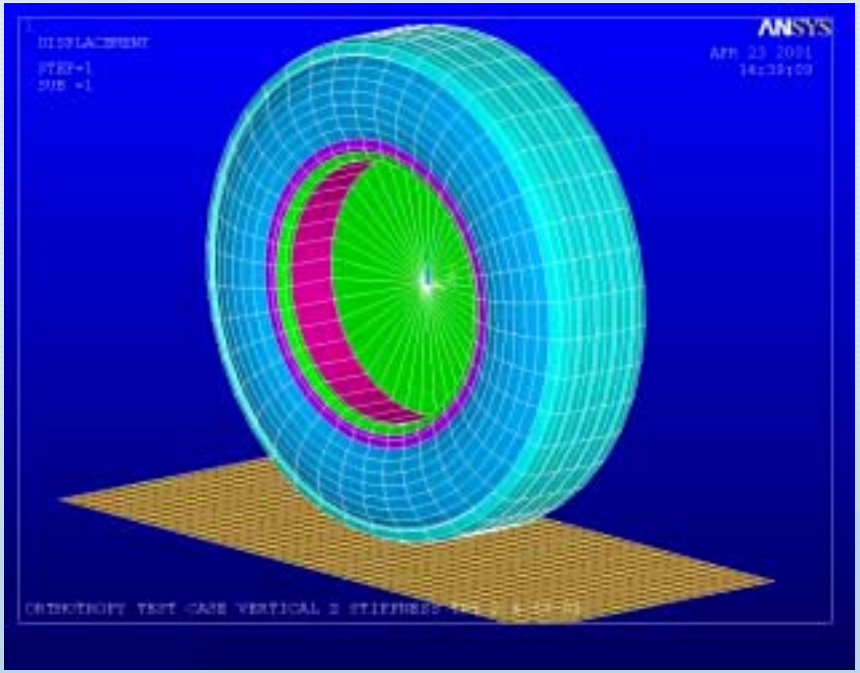
Parametric Solid Modeling Integrated with FEA and Design of Experiments



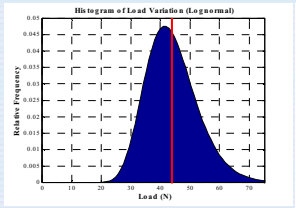
Parametric Model
linked to
Design of Experiments

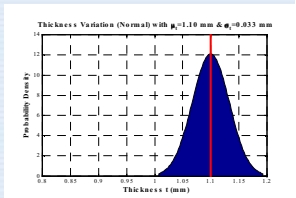
"EAGLE" Supercomputer
3600 CPU hours

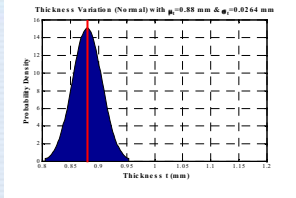
Highly non-linear structural FEA

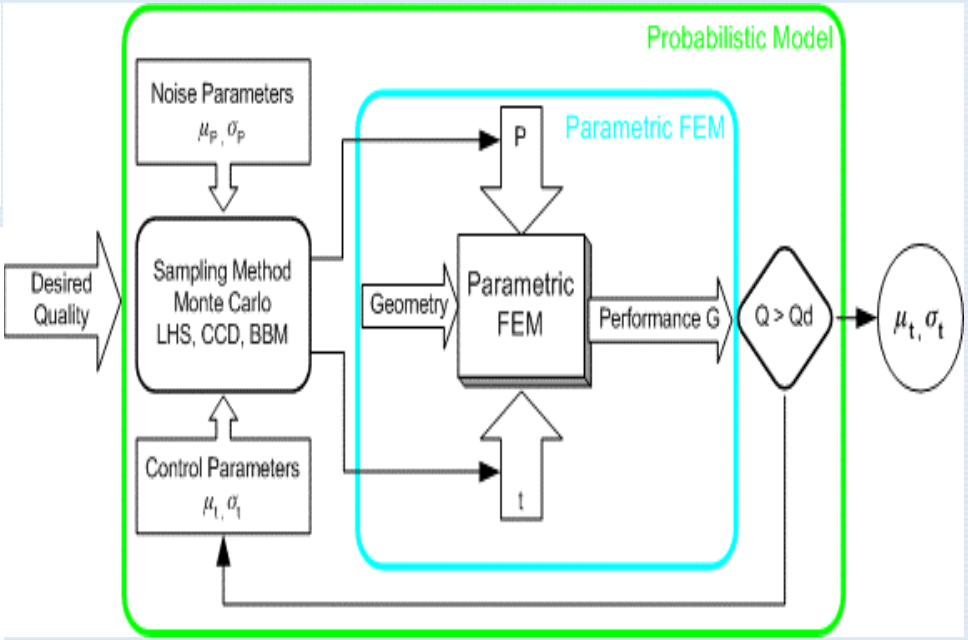


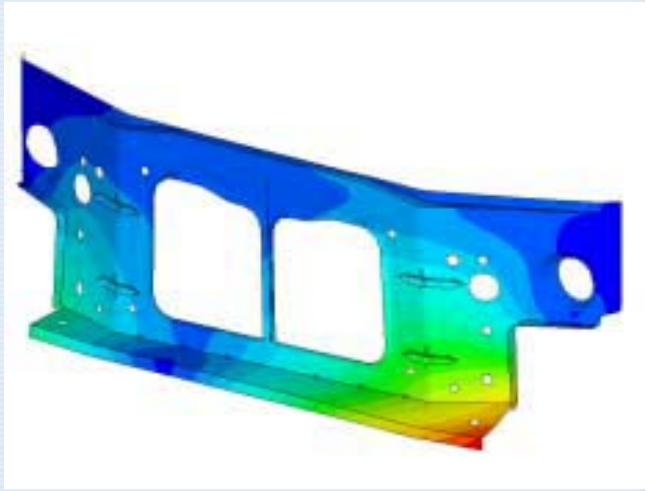
Robust Optimization for Weight Reduction and 6σ Quality



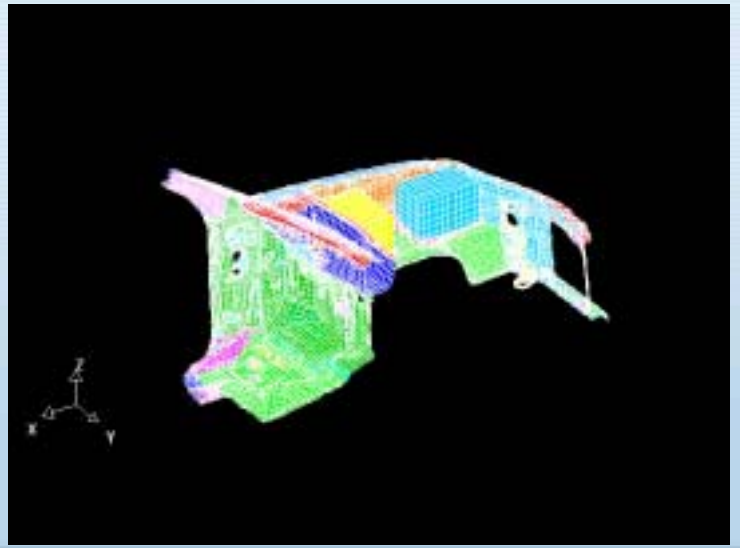








Parametric FEA Integrated with Statistical Sampling of Input Parameter Distributions (material properties, load distributions, manufacturing variations) for Lightweight Designs with 6 σ Quality

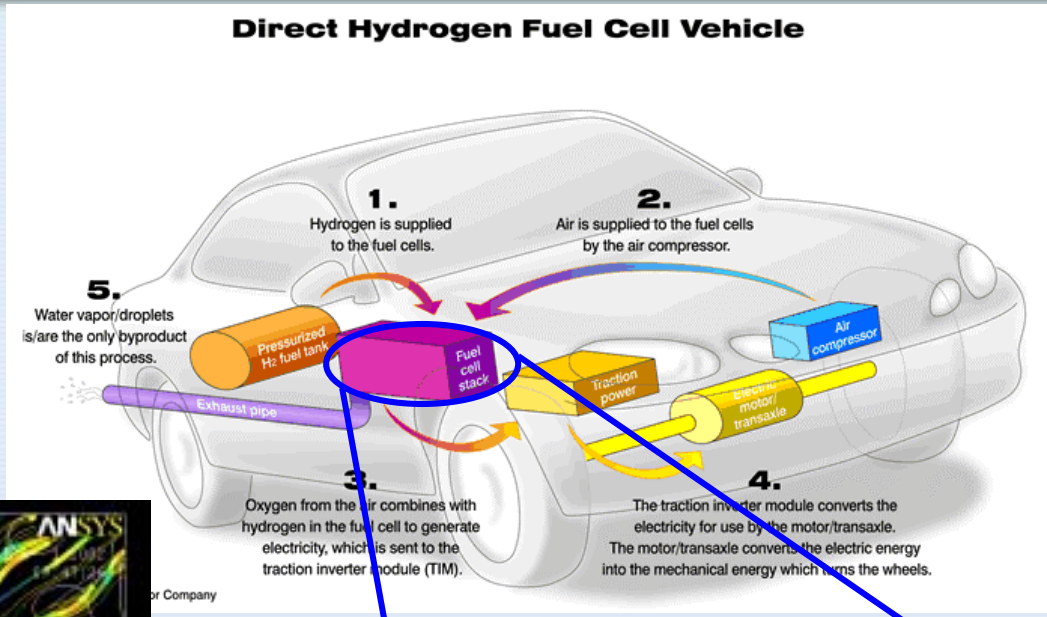


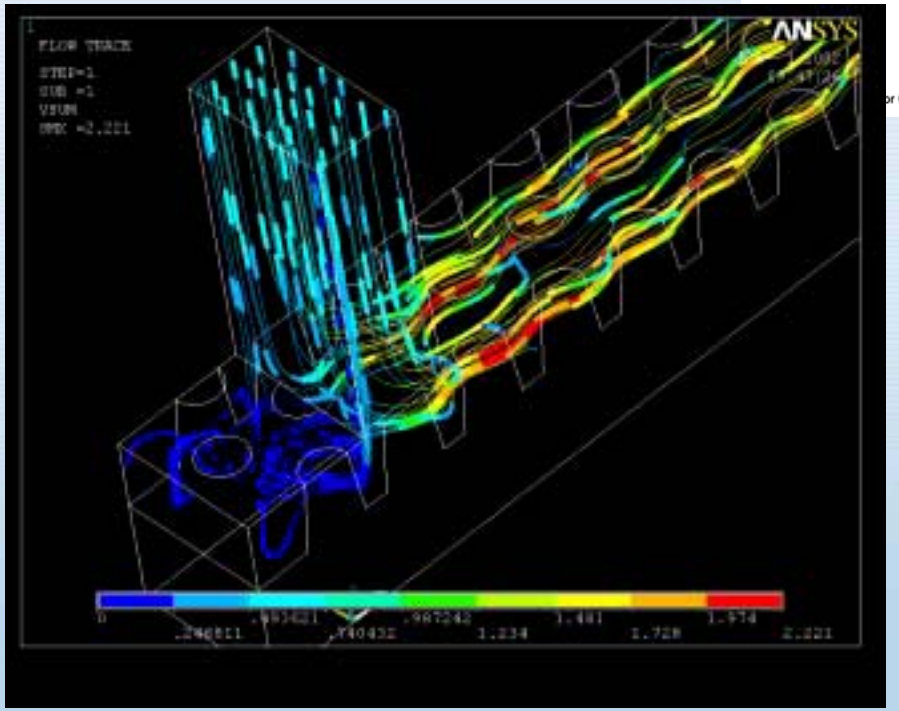
Enabling Critical Technologies

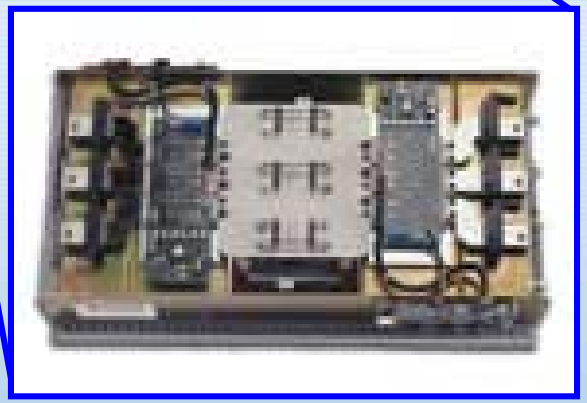
thermal management of critical components

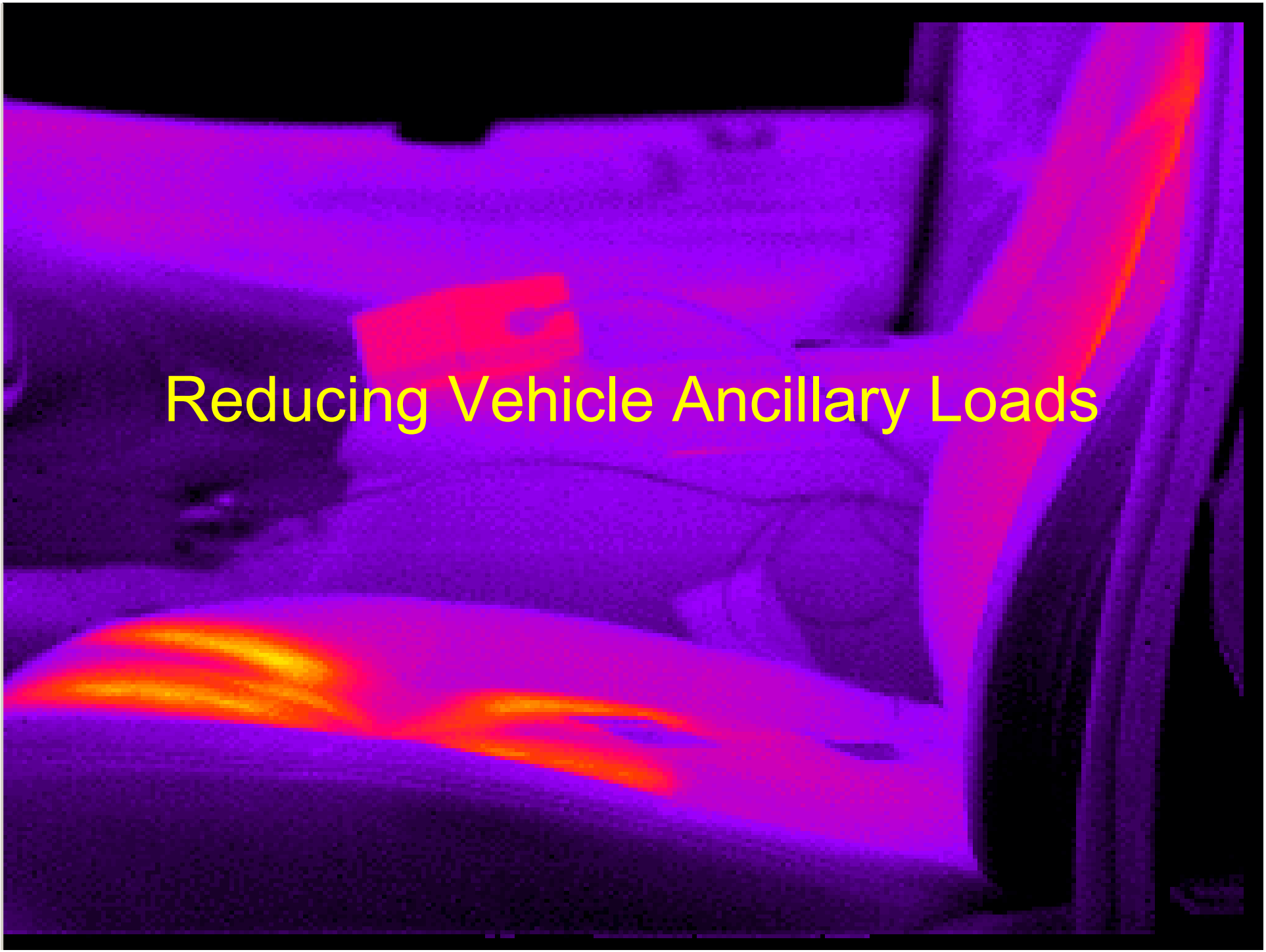
Multi-Physics Modeling

conjugate solutions of thermal,
structural,
fluid-flow,
electromechanical problems



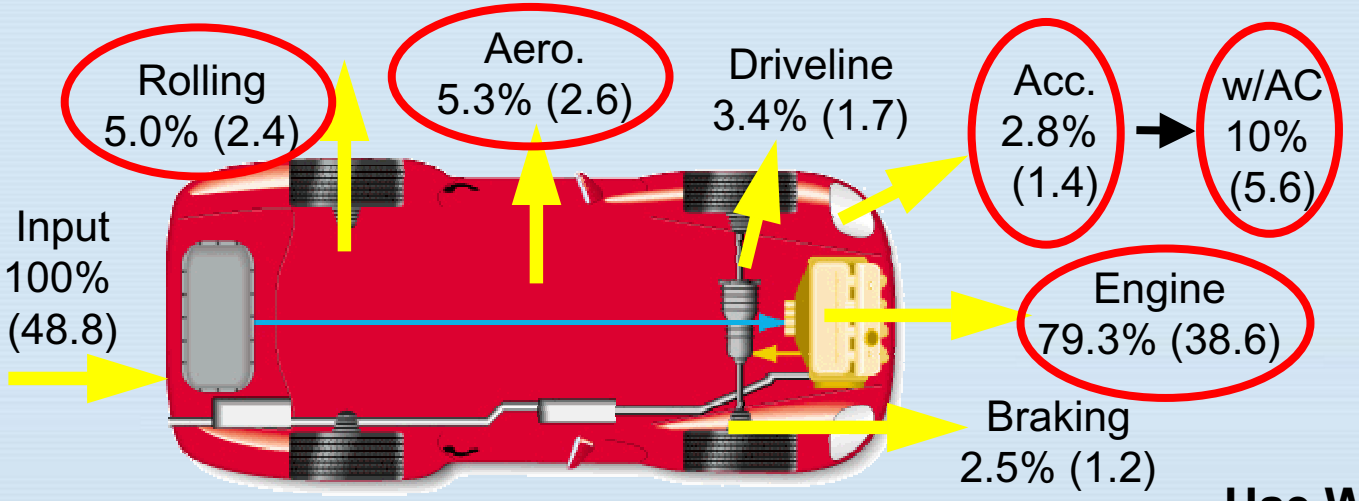





Reducing Vehicle Ancillary Loads

Where Does the Energy Go?

Reduce Size of Existing AC Systems



21.3 city, 39 highway: 26.7 mpgge

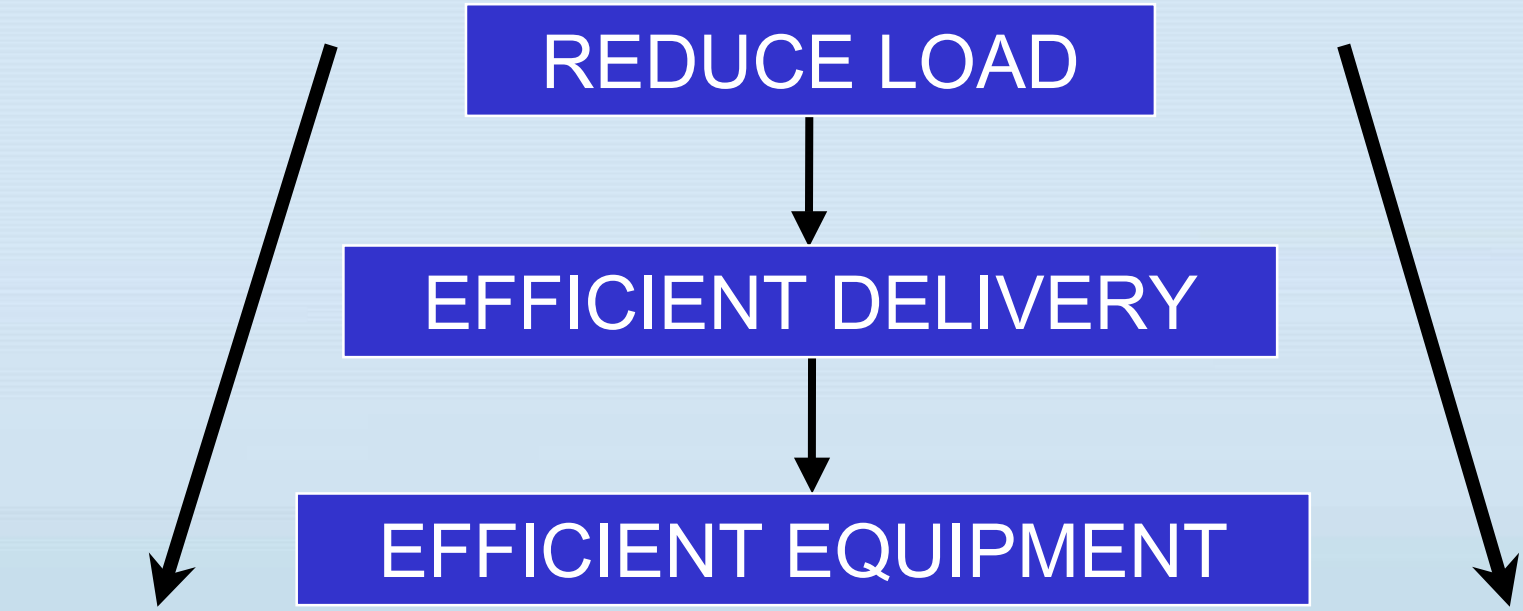
Use Waste Heat to Power Alternative AC Systems

Conventional Vehicle Energy Use for Composite FTP & Highway, (MJ)

Systems Approach

Traditional Approach - Equipment Emphasis

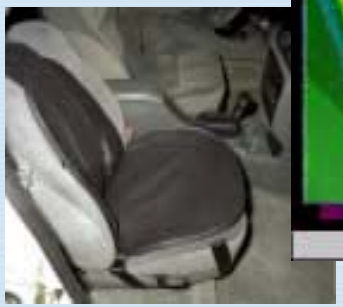
VERSUS

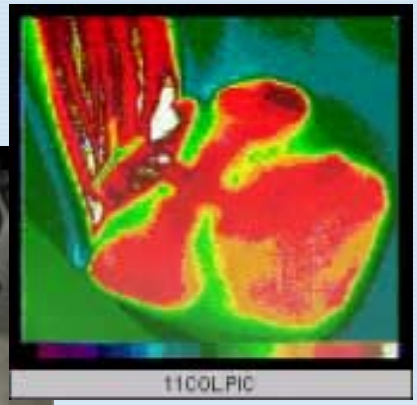


Decreases in load have a larger impact on fuel use due to equipment and delivery losses.

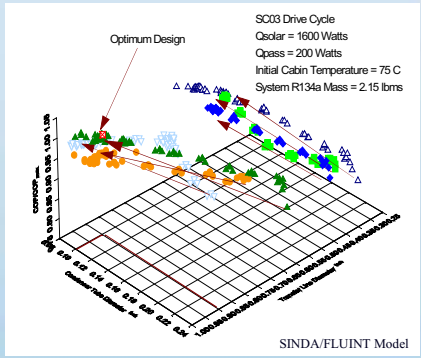
What Can Be Done?

- Reduce Load
  - Solar Reflective Glazing
  - Body Insulation
  - Parked Car Ventilation

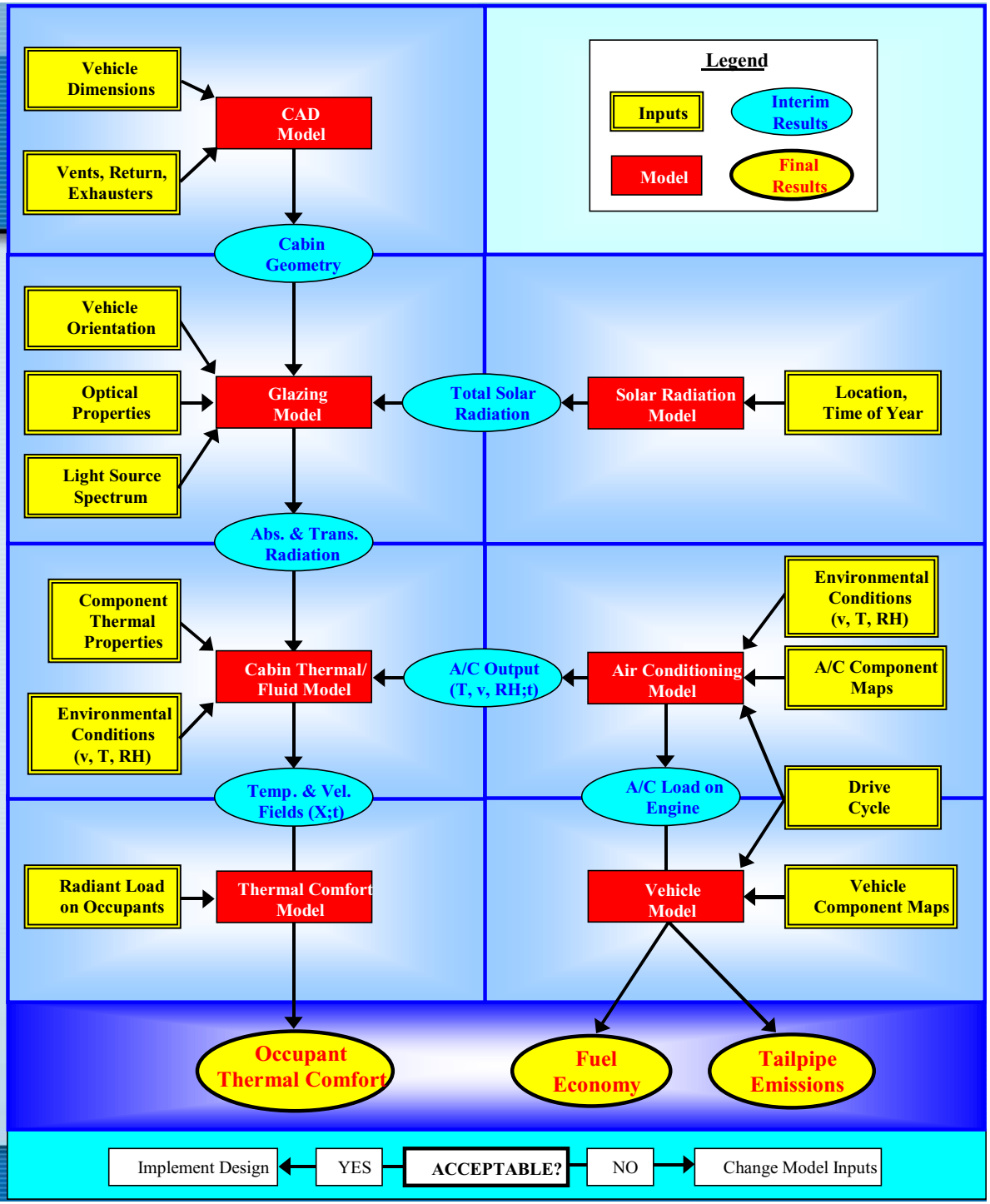




- Efficient Delivery
  - To the occupant
- Efficient Cooling Equipment
  - Closed loop control – cabin feedback
  - Engine waste heat
  - Optimization



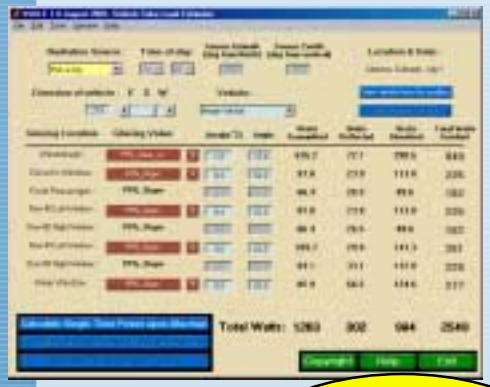
An Integrated Systems Modeling Approach Is Needed for Diverse Technology and Supplier Base



Vehicle Solar Load Estimator (VSOLE)

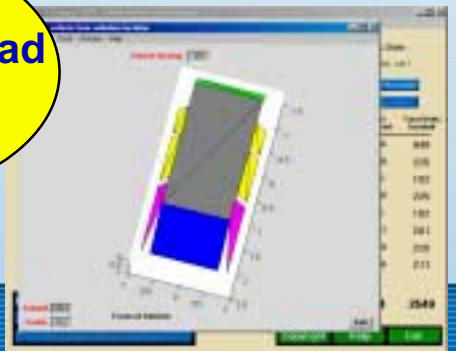
ADVISOR Linked With Many Other Models to Allow Detailed Investigation into Specific Areas

Other models generate boundary conditions for ADVISOR



Vehicle Solar Load Estimator (VSOLE)

Solar load



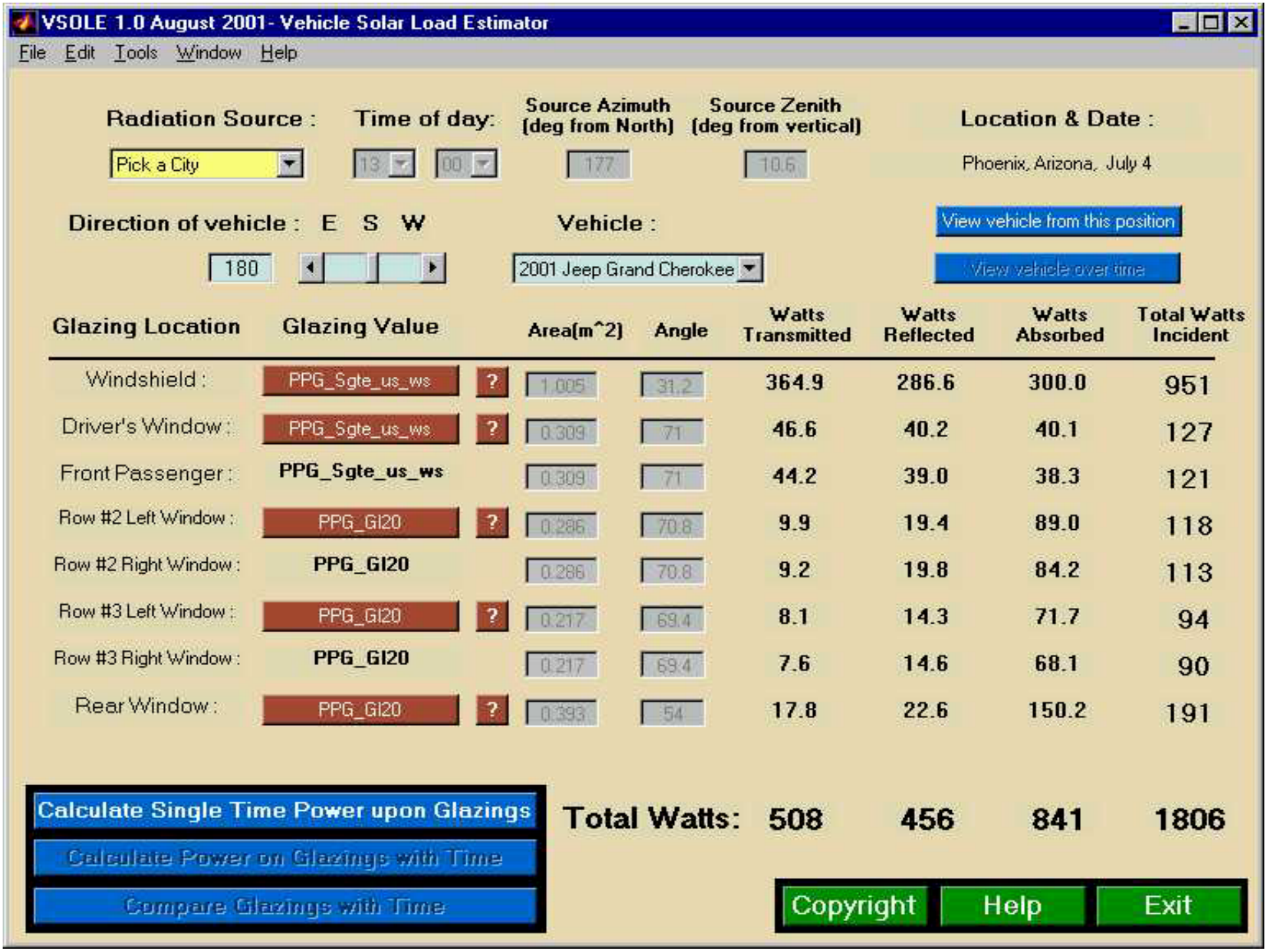
Transient A/C System Model (SINDA/FLUINT)

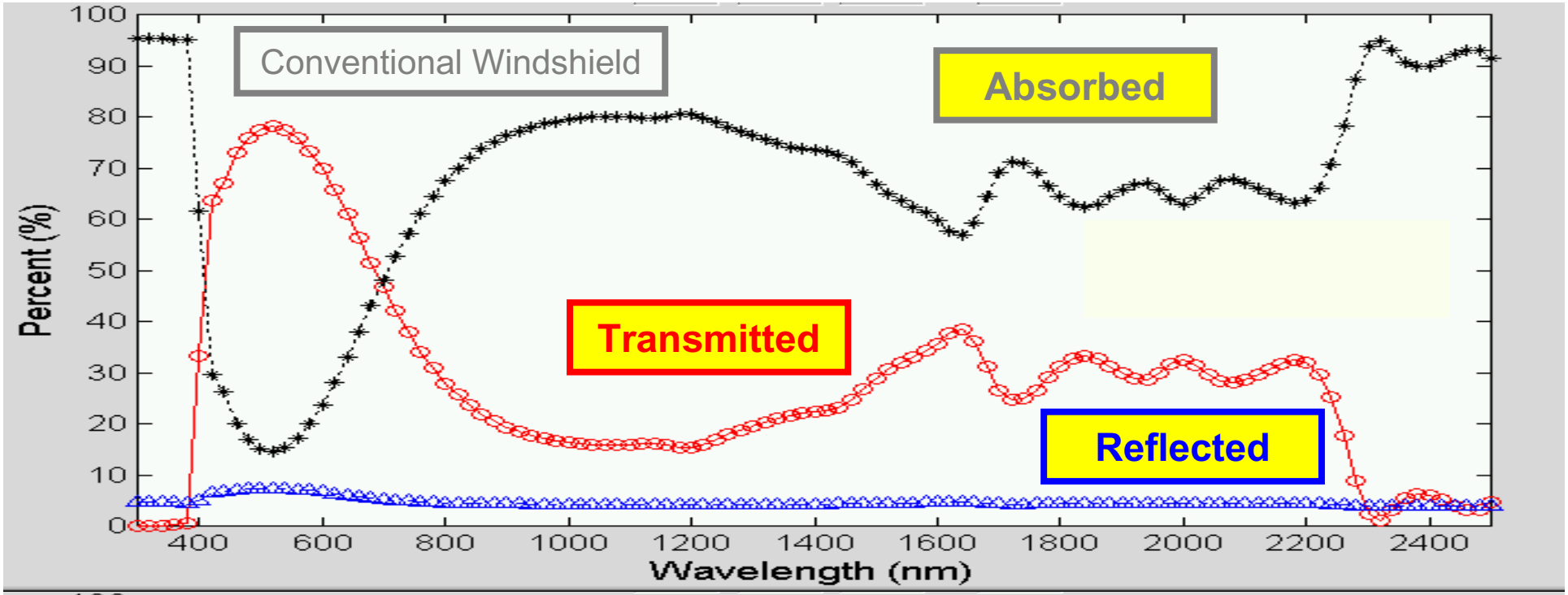
Compressor Power & cabin temp

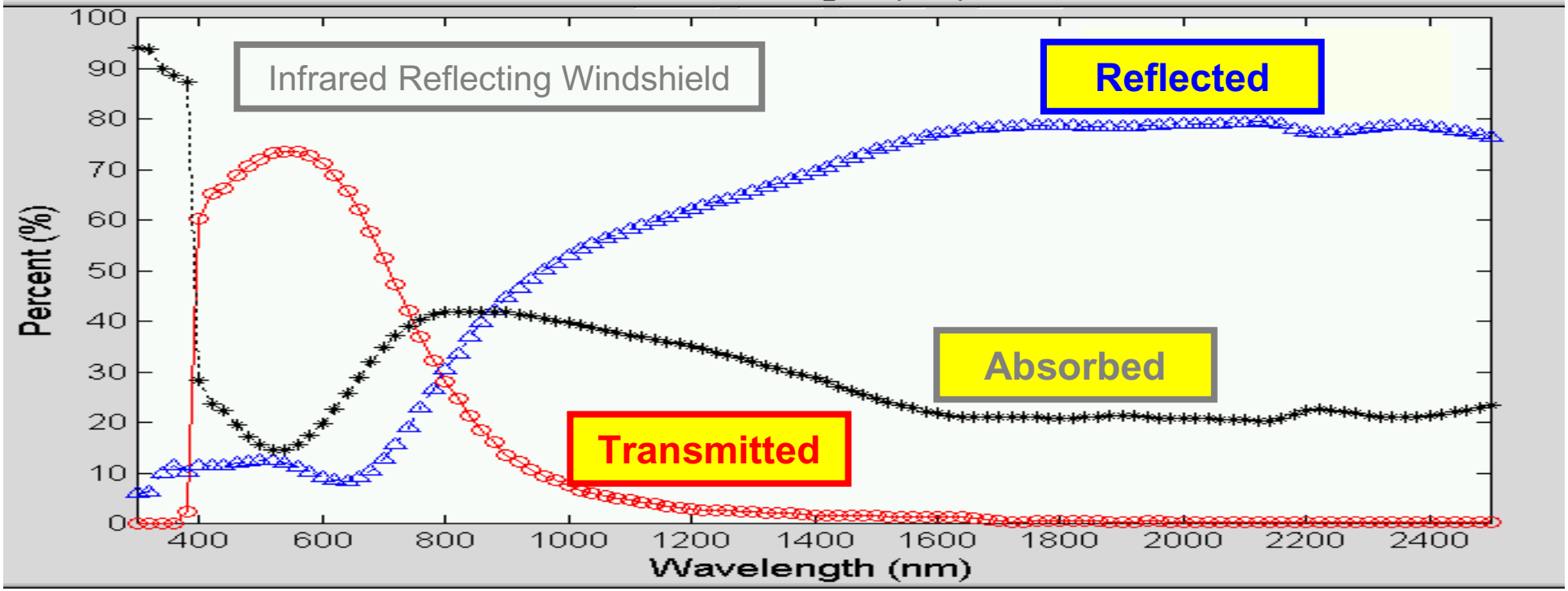
ADVISOR

VEHICLE FUEL ECONOMY

VEHICLE EMISSION TRENDS


VSOLE 1.0 August 2001- Vehicle Solar Load Estimator
File Edit Tools Window Help
Radiation Source :
Pick a City
Time of day:
13
00
Source Azimuth (deg from North)
177
Source Zenith (deg from vertical)
10.6
Location & Date :
Phoenix, Arizona, July 4
Direction of vehicle : E S W
180
Vehicle :
2001 Jeep Grand Cherokee
View vehicle from this position
View vehicle over time
Glazing Location
Glazing Value
Area(m^2)
Angle
Watts Transmitted
Watts Reflected
Watts Absorbed
Total Watts Incident
Windshield : PPG_Sgte_us_ws ? 1.005 31.2 364.9 286.6 300.0 951
Driver's Window : PPG_Sgte_us_ws ? 0.309 71 46.6 40.2 40.1 127
Front Passenger : PPG_Sgte_us_ws 0.309 71 44.2 39.0 38.3 121
Row #2 Left Window : PPG_GI20 ? 0.286 70.8 9.9 19.4 89.0 118
Row #2 Right Window : PPG_GI20 0.286 70.8 9.2 19.8 84.2 113
Row #3 Left Window : PPG_GI20 ? 0.217 69.4 8.1 14.3 71.7 94
Row #3 Right Window : PPG_GI20 0.217 69.4 7.6 14.6 68.1 90
Rear Window : PPG_GI20 ? 0.393 54 17.8 22.6 150.2 191
Calculate Single Time Power upon Glazings
Calculate Power on Glazings with Time
Compare Glazings with Time
Total Watts: 508 456 841 1806
Copyright
Help
Exit


Conventional Windshield
Absorbed
Transmitted
Reflected
Percent (%)
Wavelength (nm)
0
10
20
30
40
50
60
70
80
90
100
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400


Infrared Reflecting Windshield
Reflected
Absorbed
Transmitted
Percent (%)
Wavelength (nm)
0
10
20
30
40
50
60
70
80
90
100
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400

Results for calculated glazing loads with time and vehicle direction

File Edit Tools Window Help

Start Time: 10 00

Stop Time: 15 00

Radiation Path : Phoenix-July 6

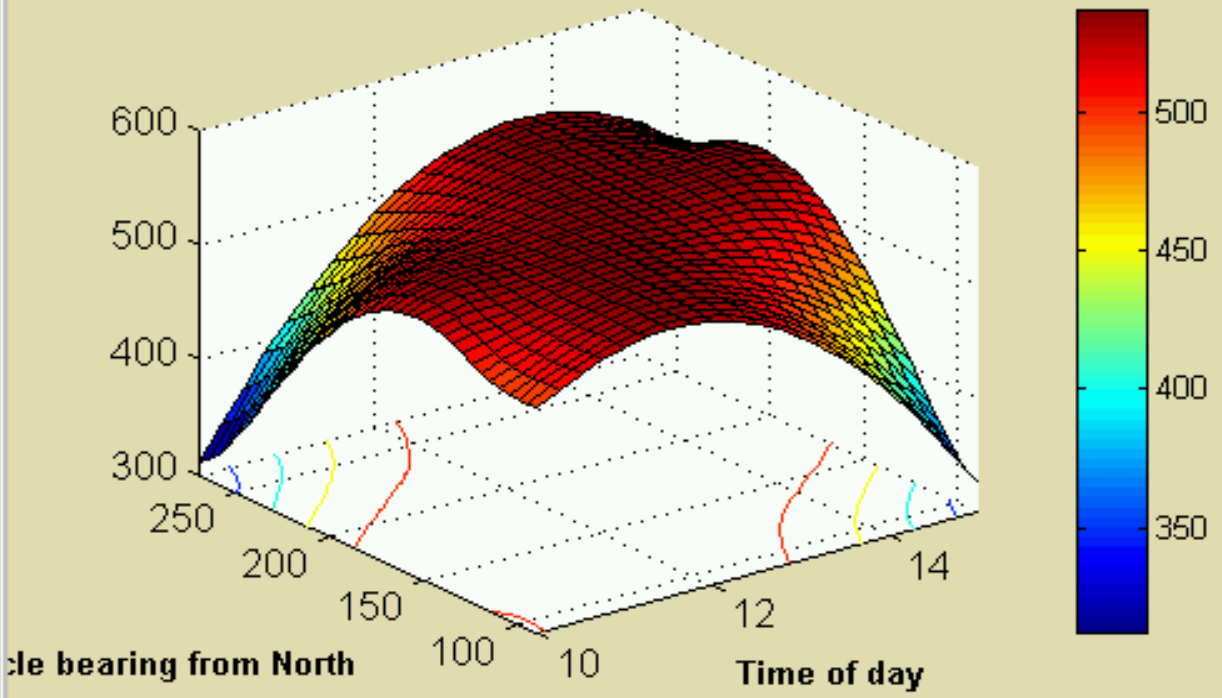
Radiation Source : Phoenix-July 6

Current Vehicle: 2001 Jeep Grand

Starting Bearing: 90

Stopping Bearing: 270

Glazing Location	Selected Glazing
Windshield :	PPG_Sgte_us_ws
Drivers :	PPG_Slrgrn
Front Passenger:	PPG_Slrgrn
Row #2 Left:	PPG_GI20
Row #2 Right:	PPG_GI20
Row #3 Left:	PPG_GI20
Row #3 Right:	PPG_GI20
Rear Window :	PPG_GI20



Plot : Total Power

Power : Transmitted

Plot type

- (•) 3-D Surface Contour
- ( ) 3-D Swap X-Y Axis
- ( ) 2-D Color Contour

Number of Contour Lines 10

Calculate

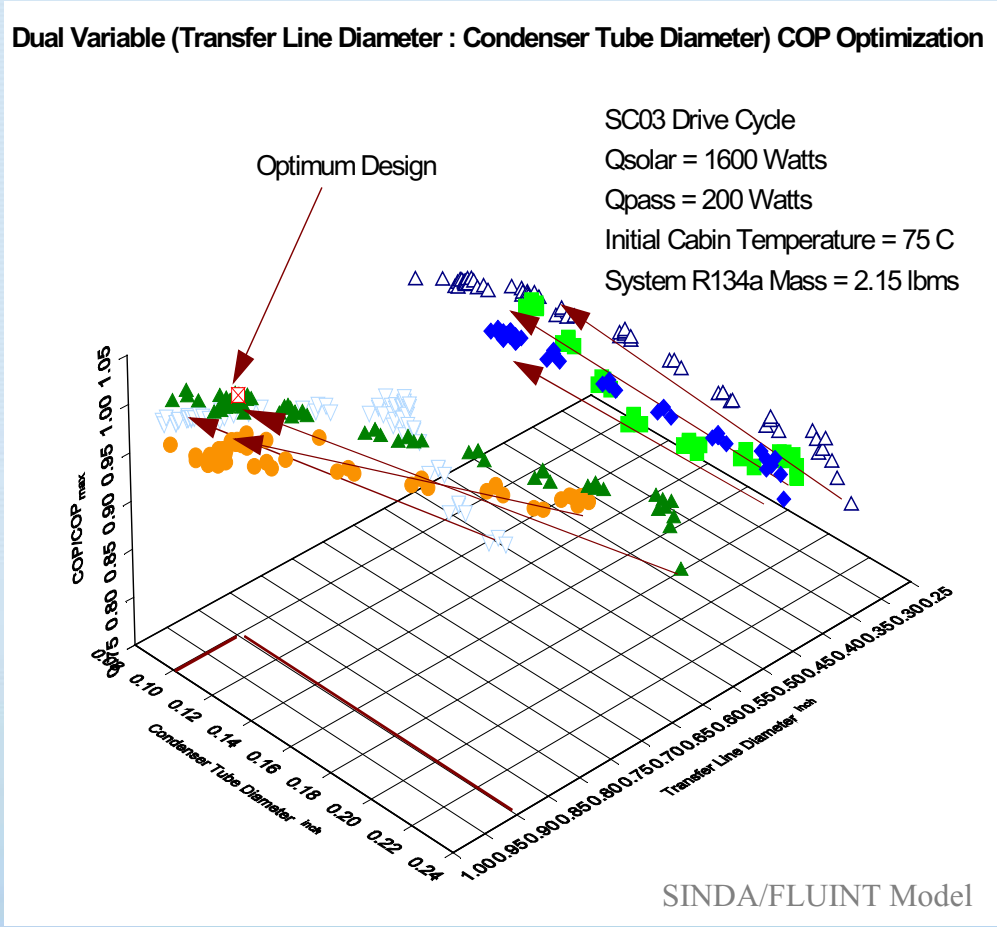
Cancel/Change Parameters

Vehicle A/C Modeling

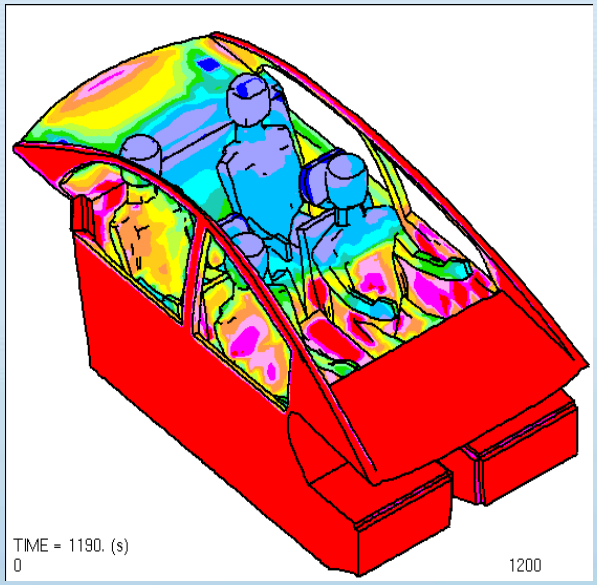
A/C System COP Optimization

- System Perspective
- Two-Phase Flow in Condenser and Evaporator
- Strongly Dependent on Multiple Variables
- Single Variable Optimization Inaccurate

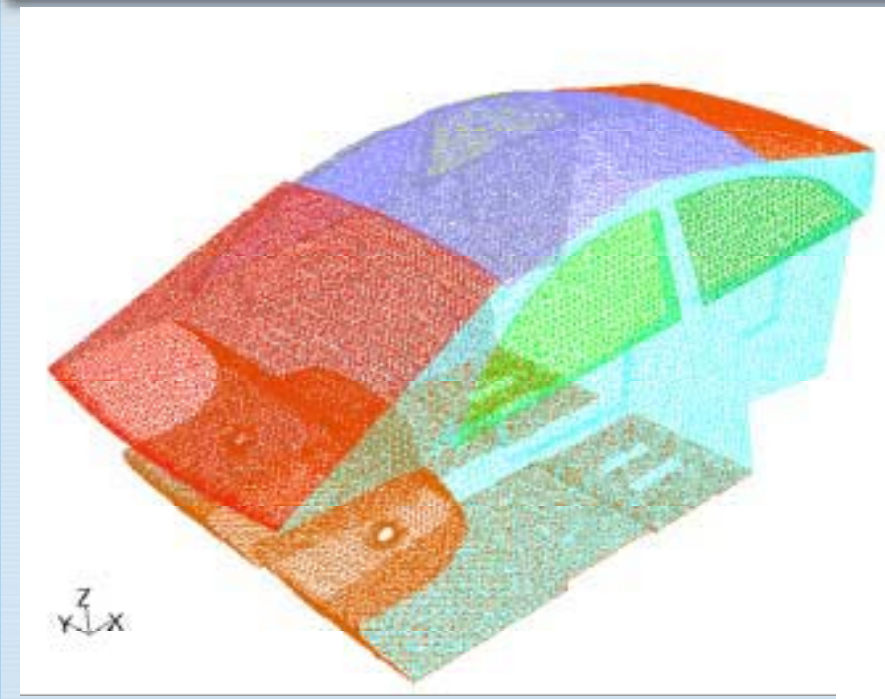
COP Maximization vs. Transfer Line Diameter and Condenser Tube Diameter

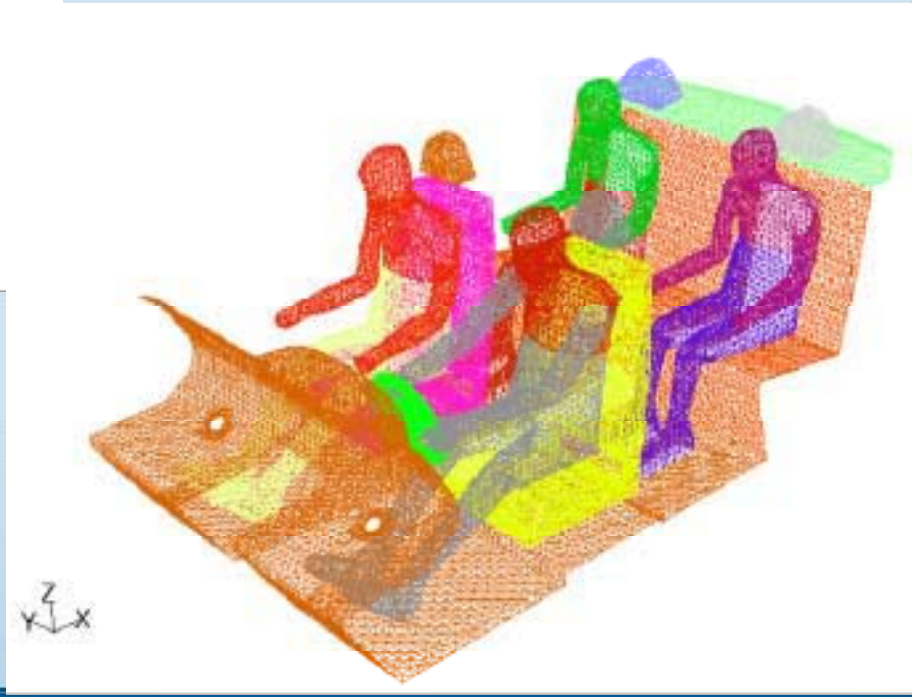


Vehicle CAD and Thermal/Fluid Modeling



Vehicle Mesh – 450,000 cells



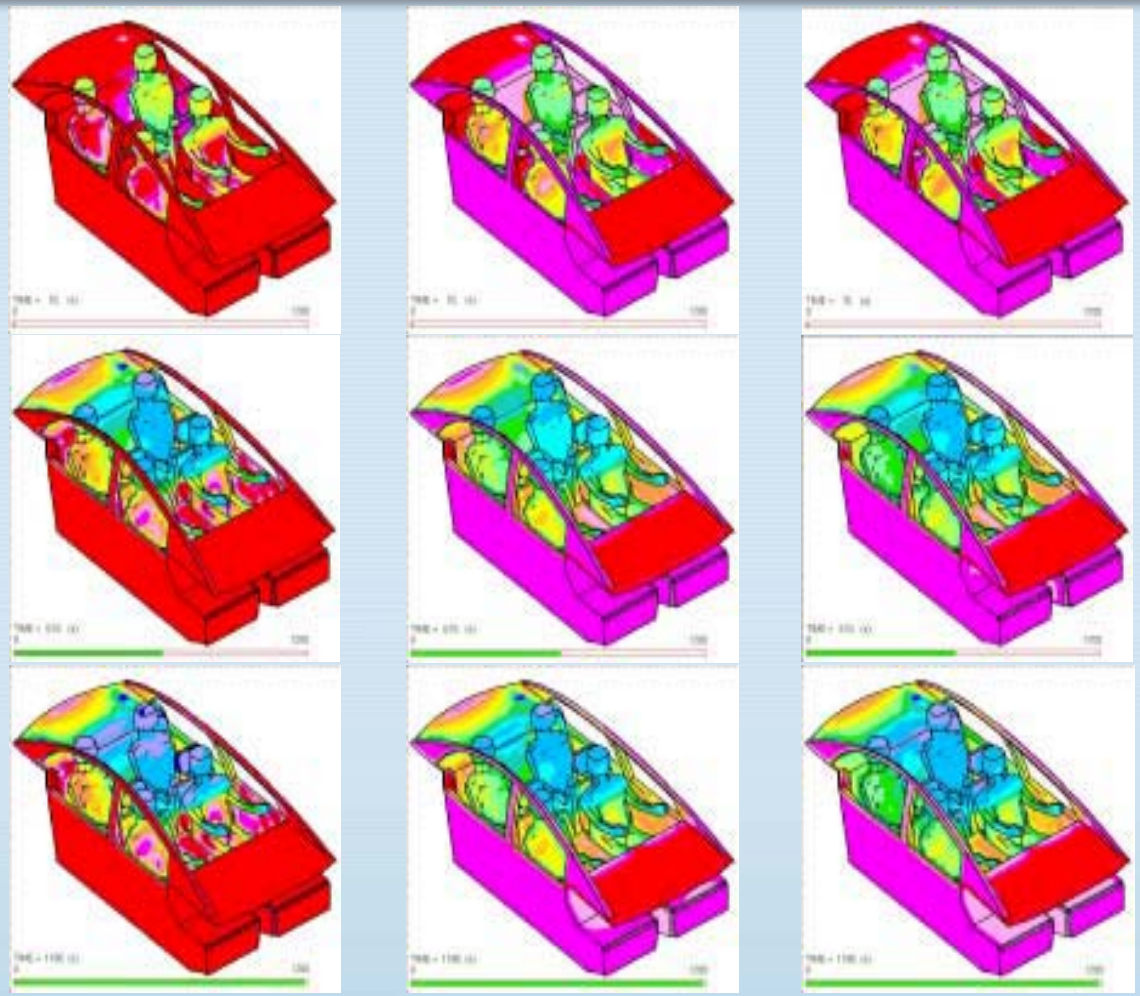


Results - 0, 10, and 20 minutes

T=10s

T=610s

T=1190s

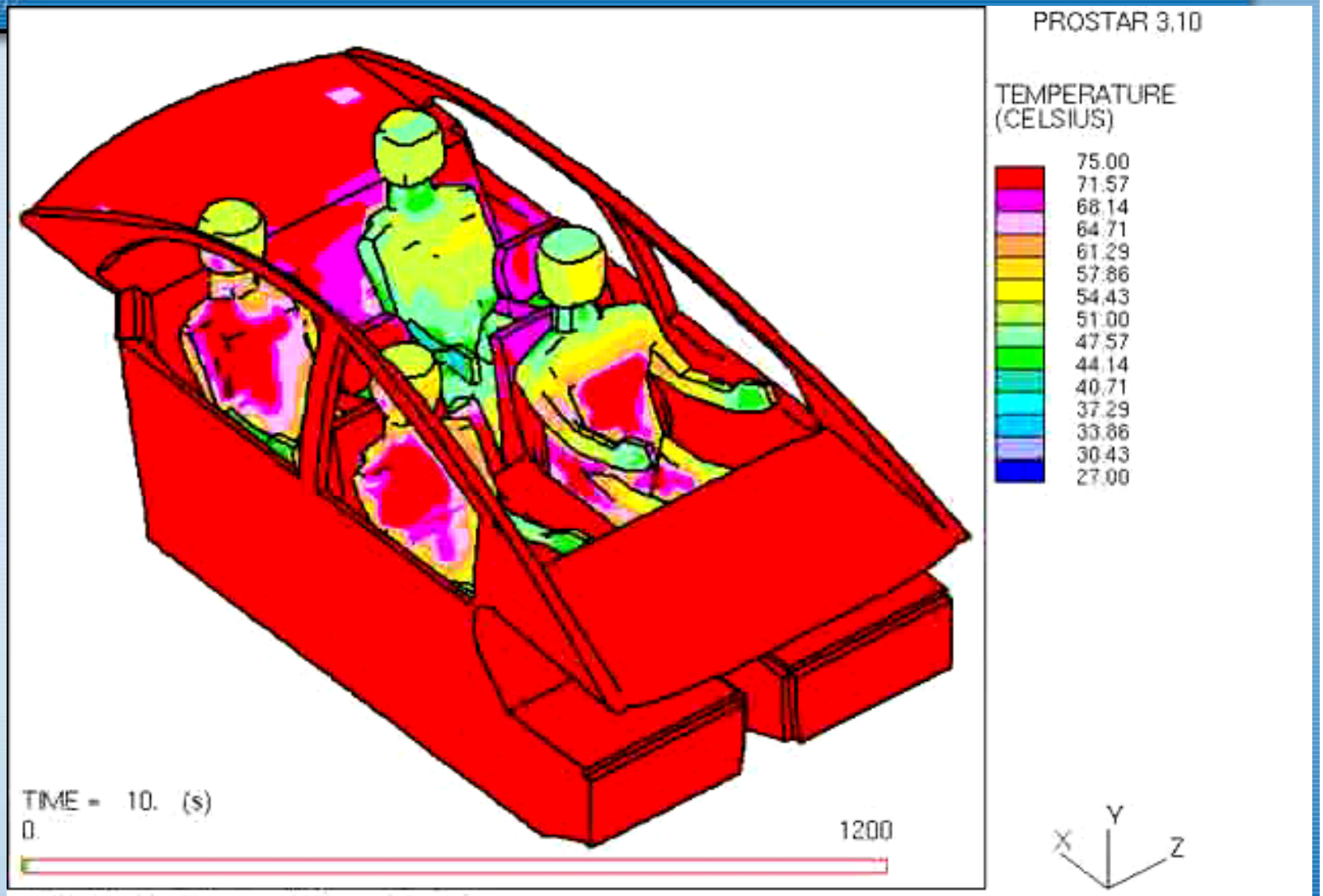


Conventional Glass

Solar Windshield
Reduced A/C

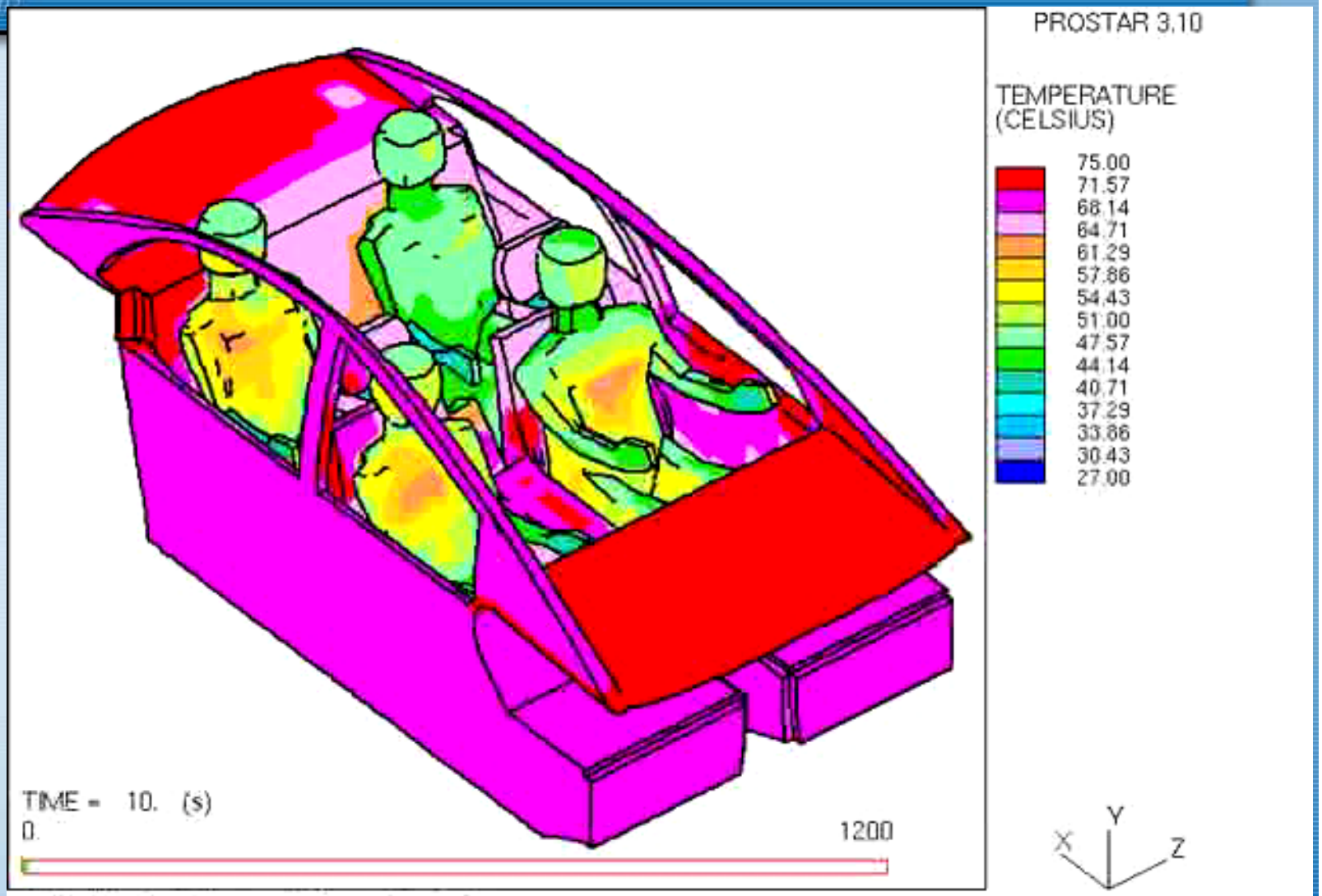
All Solar Glass
Reduced A/C

Cabin with Conventional Glazing



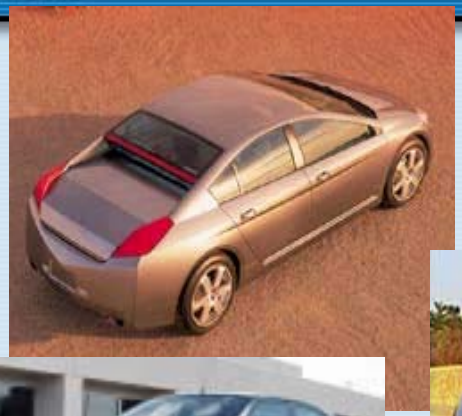
Cabin Interior Airflow and Thermal Analysis
Time Variation of Temperature Distribution
(Case #1 Top View)

Cabin with Solar Reflective Glazing



Cabin Interior Airflow and Thermal Analysis
Time Variation of Temperature Distribution
(Case #3 Top View)

NREL's Industry Partnerships

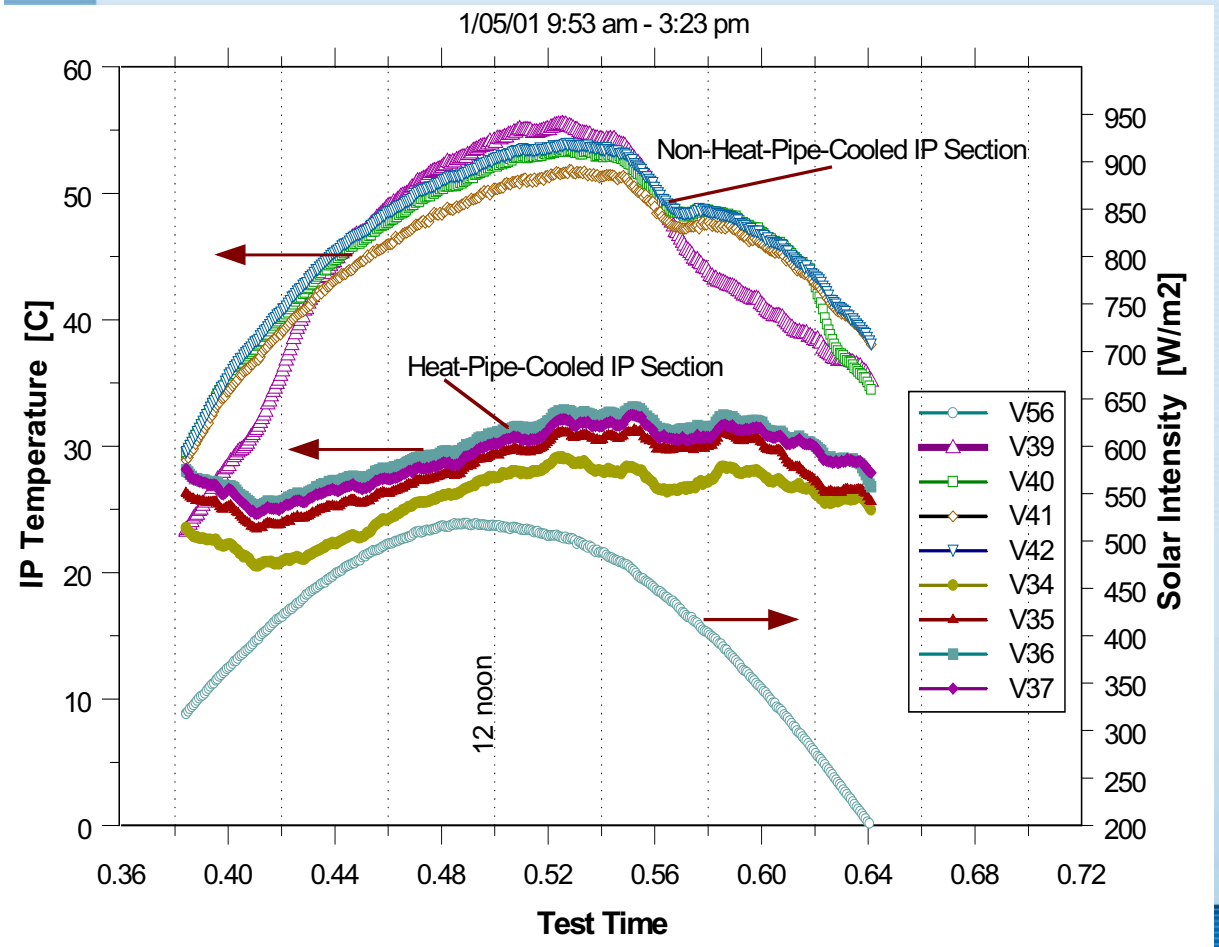






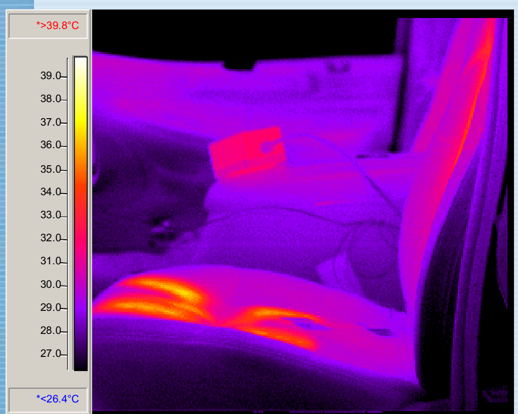


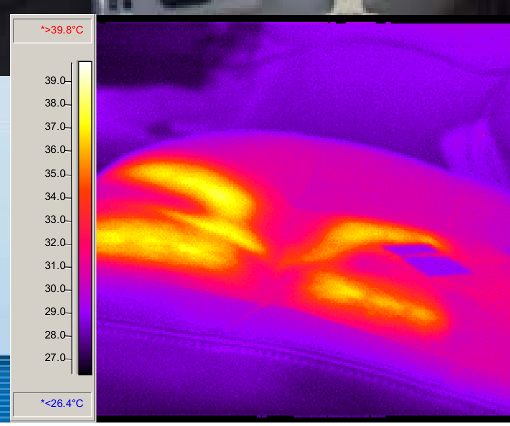

Heat Pipe I.P. Test

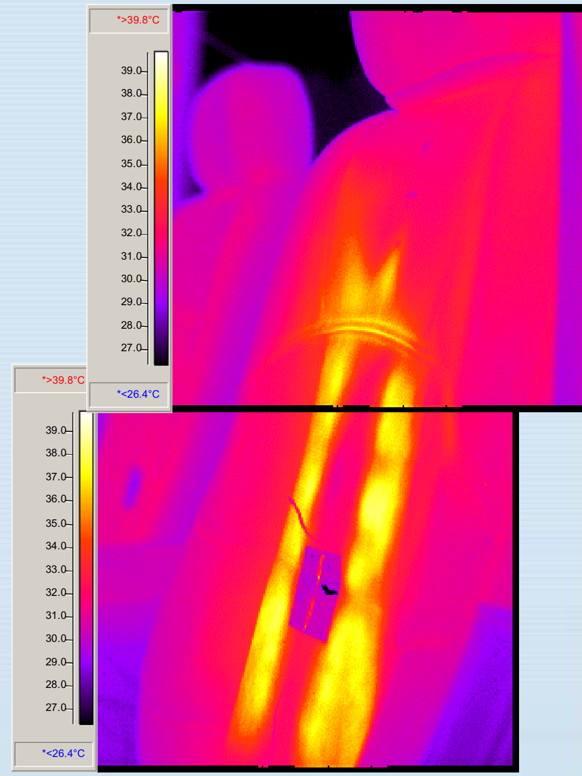


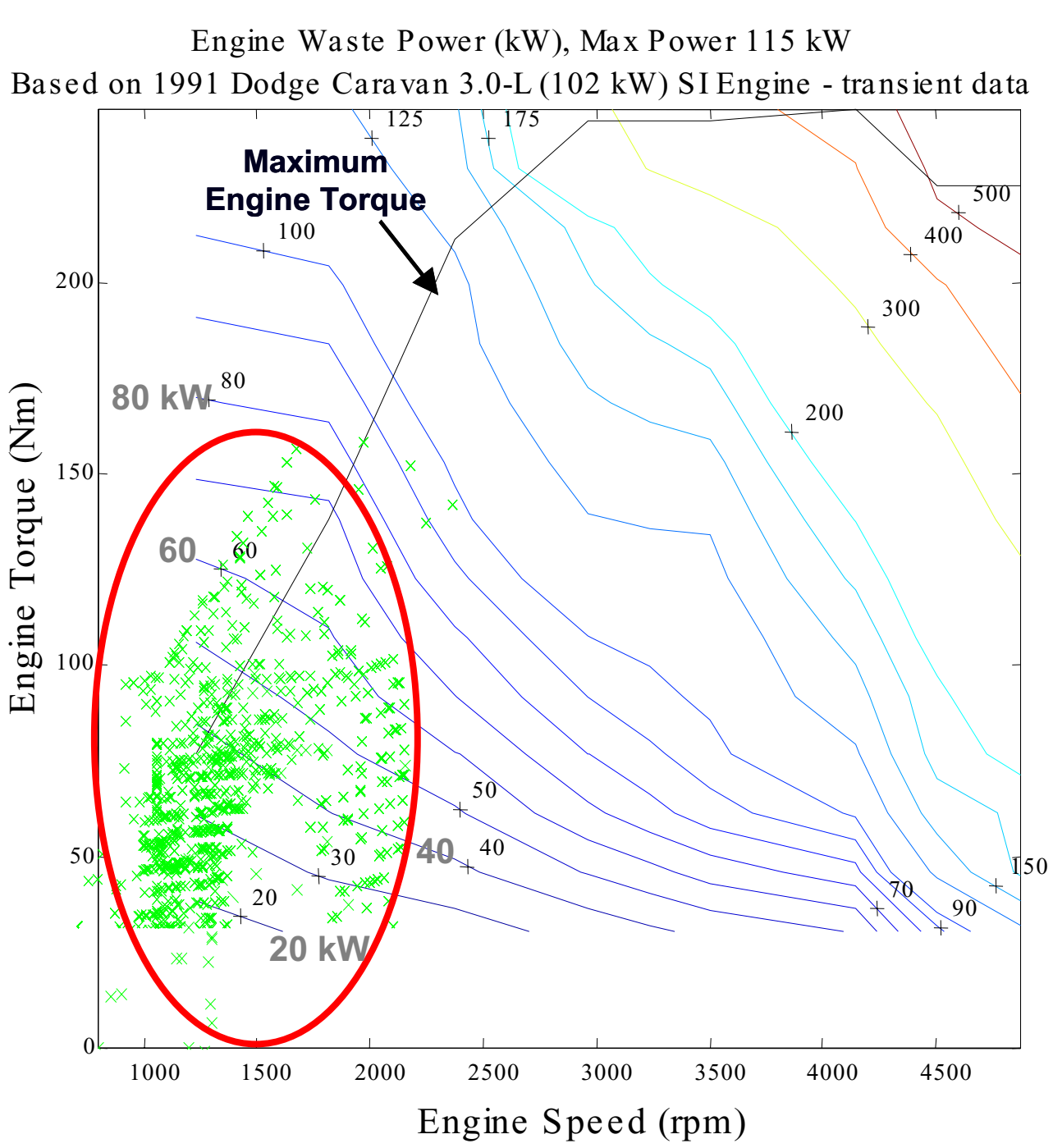
Efficient Delivery: Heated/Cooled Seats

25 Years of Research Excellence 1977-2002

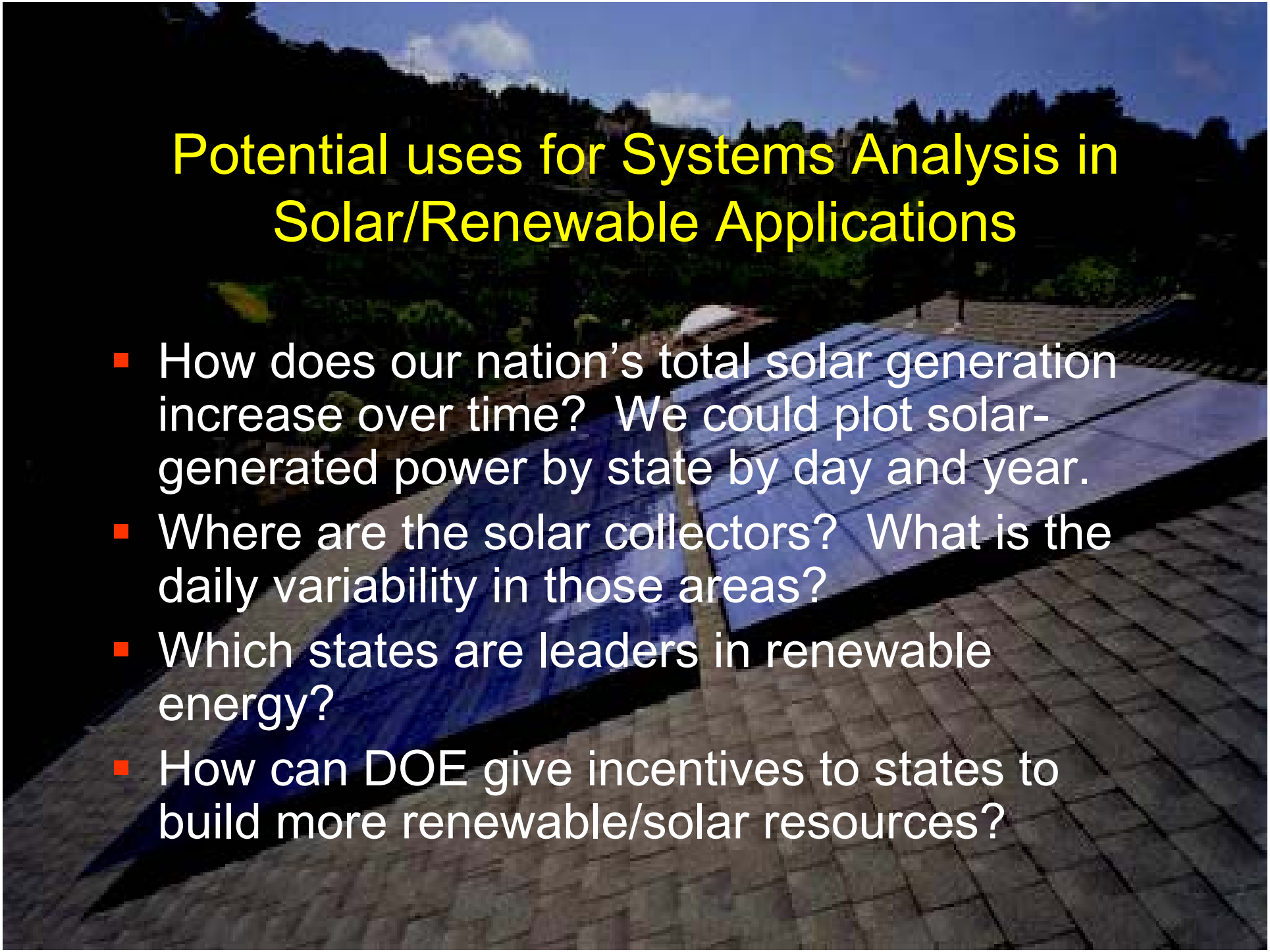








Available Engine Waste Heat (23 kW avg over FTP)



Potential uses for Systems Analysis in Solar/Renewable Applications

- How does our nation's total solar generation increase over time? We could plot solar-generated power by state by day and year.
- Where are the solar collectors? What is the daily variability in those areas?
- Which states are leaders in renewable energy?
- How can DOE give incentives to states to build more renewable/solar resources?


On Target for a Systems Approach
Opportunities surround you
Use existing resources
Industry partnerships can play a big role
Ask the right questions
Think outside the box – be creative!