National Renewable Energy Laboratory
Innovation for Our Energy Future

Duty Cycle Analysis & Tools:
Maximizing Vehicle Performance

High Efficiency Advanced Trucks Session

HTUF 2009 – Atlanta, GA

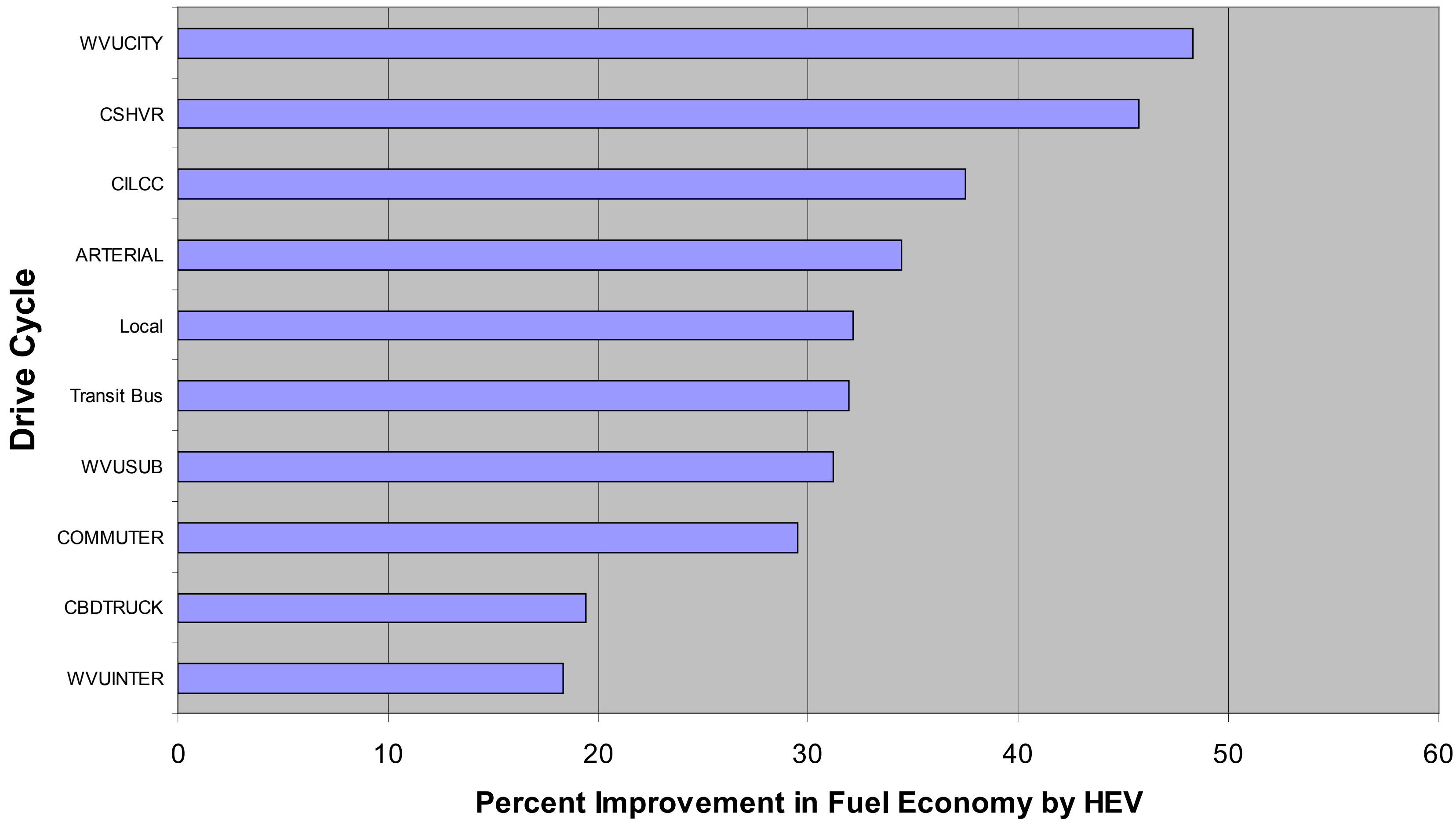
October 28, 2009

Kevin Walkowicz – NREL Advanced Vehicle Testing Activity

NREL/PR-540-46972

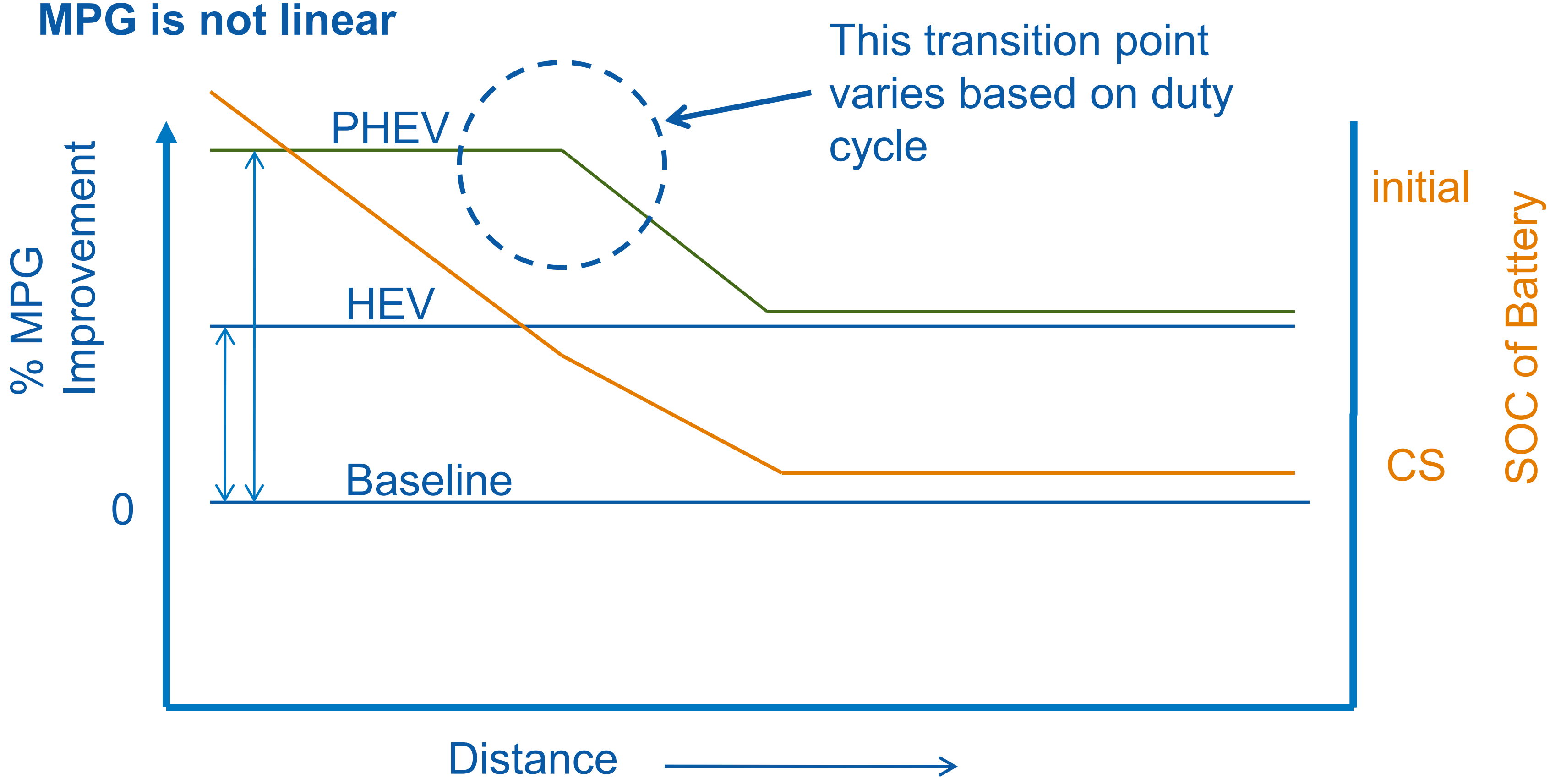
Duty Cycle Affects MPG and Emissions!

Example of HEV improvement in fuel economy over various duty cycles:



It gets more complicated with PHEV's!

Add in another factor: distance driven on a given drive cycle – MPG is not linear



You'll now need to know:

1) What type of cycle do I have? <u>and</u>
2) How long do I drive on that cycle in order to calculate mpg?

So, Who Should Care and Why? Top 3 Questions in Each Area

Fleets:

- When considering a large purchase of advanced technology vehicles:
  1. What benefit will this technology have in *'my'* fleet?
  2. What's the payback?
  3. Where should I place the vehicles in my fleet?

OEM's:

- When designing a system:
  1. What is the range of performance observed for the vehicle type ?
  2. What should we target our design for? (component sizing, control, etc)
  3. How should we test the vehicle?

Regulators/Funding Agencies:

- When considering funding implementation:
  1. What is 'real' benefit in a fleet?
  2. How to assign vehicle HEV credits?
  3. Do we need to target specific locations or routes?

All These Important Questions…

Fleets:

- When considering a large purchase of advanced technology vehicles:
  1. What benefit will this technology have in *'my'* fleet?
  2. What's the payback?
  3. Where should I place the vehicles in my fleet?
  4. Will the performance of the vehicle in my fleet match that of others?

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Regulators:

- When considering funding implementation:
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  2. Is the benefit claimed legitimate?
  3. Do we need to target specific locations or routes?

All These Important Questions…

Fleets:

- When considering a large purchase of advanced technology vehicles:

The answer to all these questions: It depends on the Duty Cycle

s?

O

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Why is this important to Fleets?

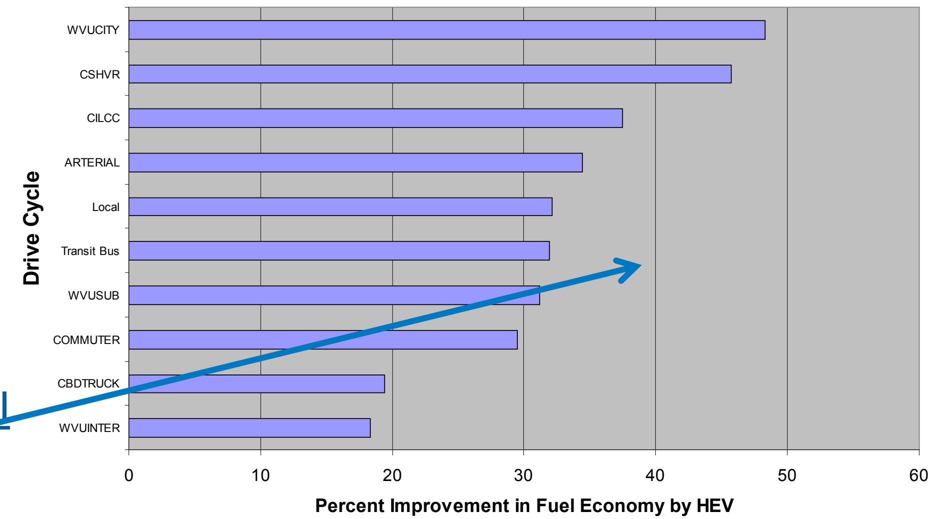
Example: What is the payback?

Typical Example: Purchase a ‘traditional’ truck or an ‘HEV’? The ‘HEV’ costs $25k more. It’s driven 20,000 miles per year and it currently gets 10 mpg. Fuel =$3.00/gal.

(Cost = $6,000/vehicle/yr)

- If the HEV gets a <u>+10%</u> improvement (11 mpg) the payback through fuel reduction is roughly <u>46 years</u> ($5400/vehicle/year)
- If the HEV gets a <u>+50%</u> improvement (15 mpg) my payback (through fuel reduction) is roughly <u>12 ½ years</u> ($4000/vehicle/year)

<u>Bottom Line: you’d better know where you’ll fall on fuel economy before you invest!</u>

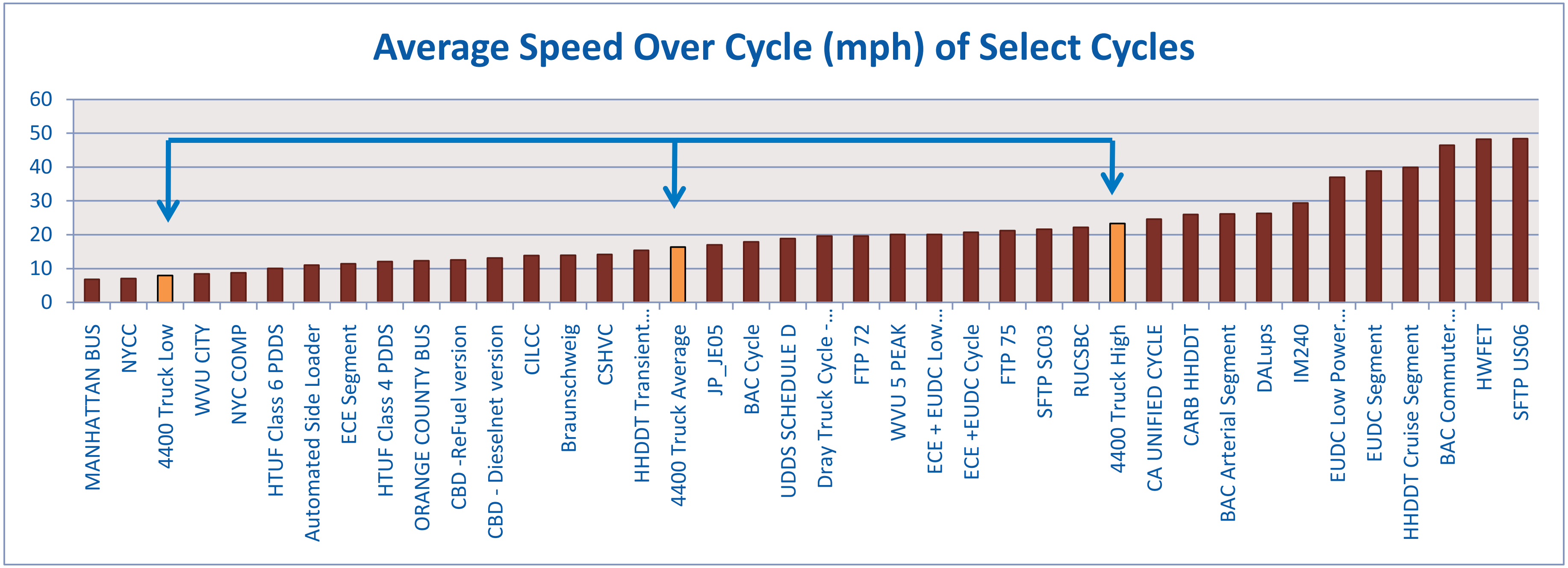


EPA Window Sticker: ‘Actual mileage may vary’!

Why is this Important to Fleets?

Example: Where should I place the vehicles in my fleet?

Example: One fleet might have a large variation in drive characteristics and it might not make sense to place vehicles on certain routes.



Why is this Important to OEMs?

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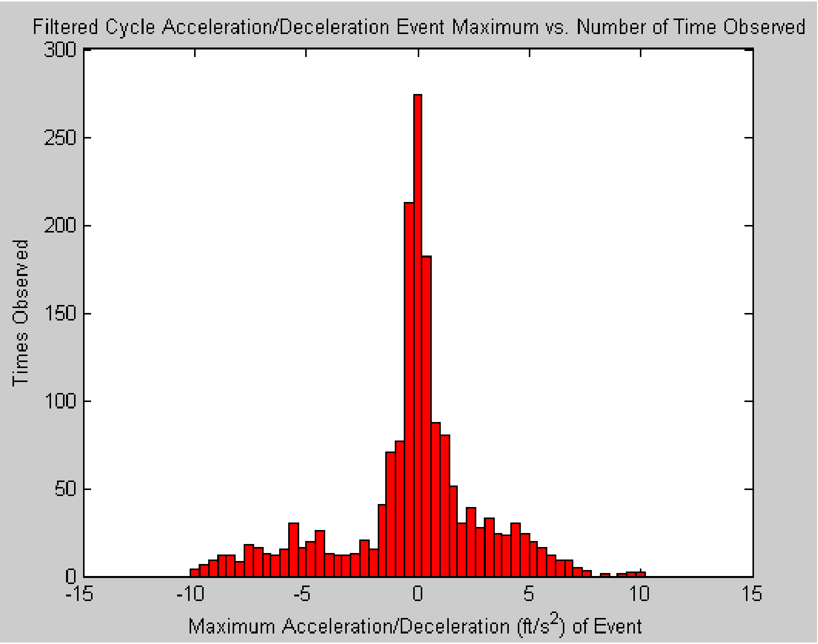

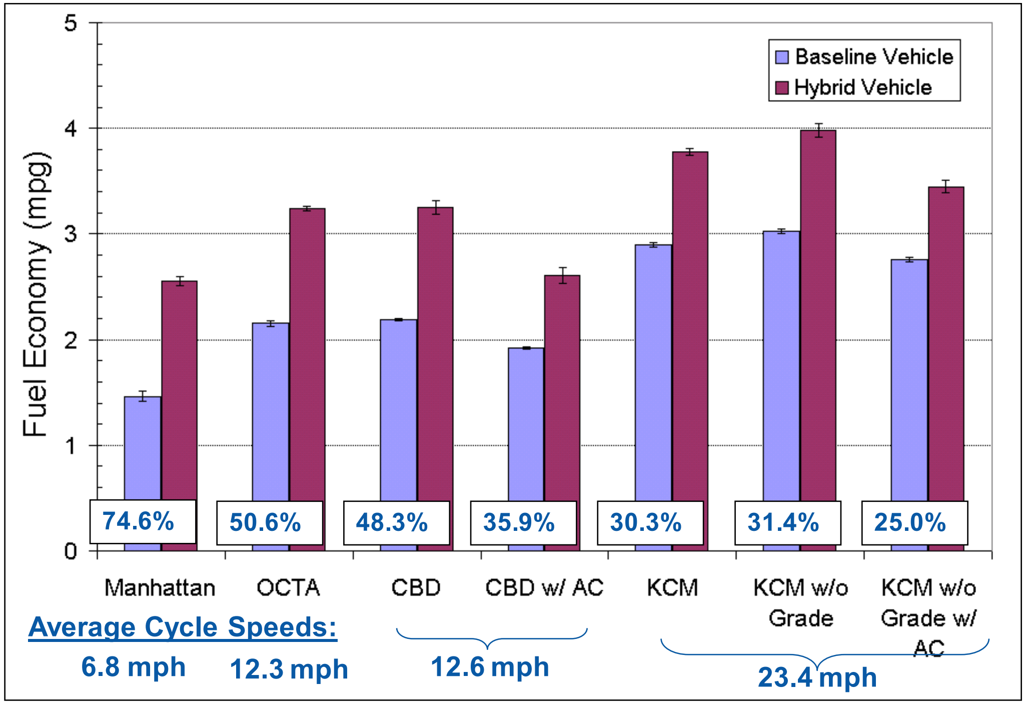

Why is this important to funding agencies?

Example:

- When considering funding implementation:
  1. What is 'real' benefit in a fleet?
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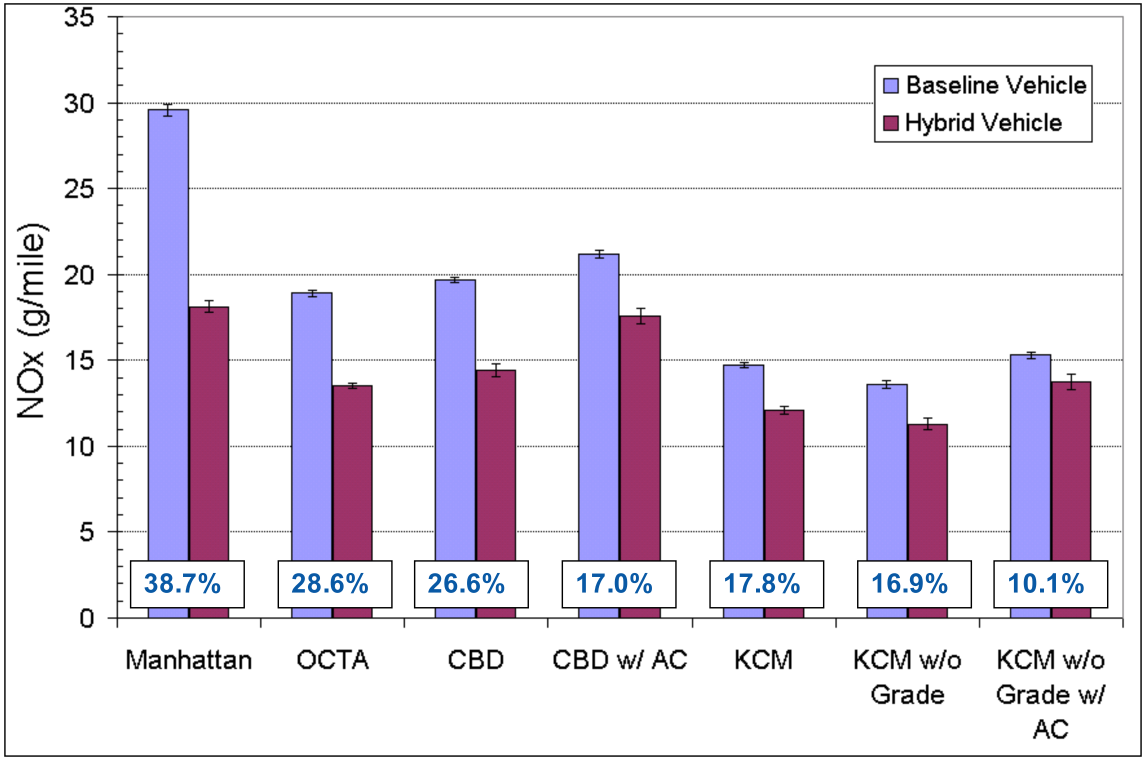
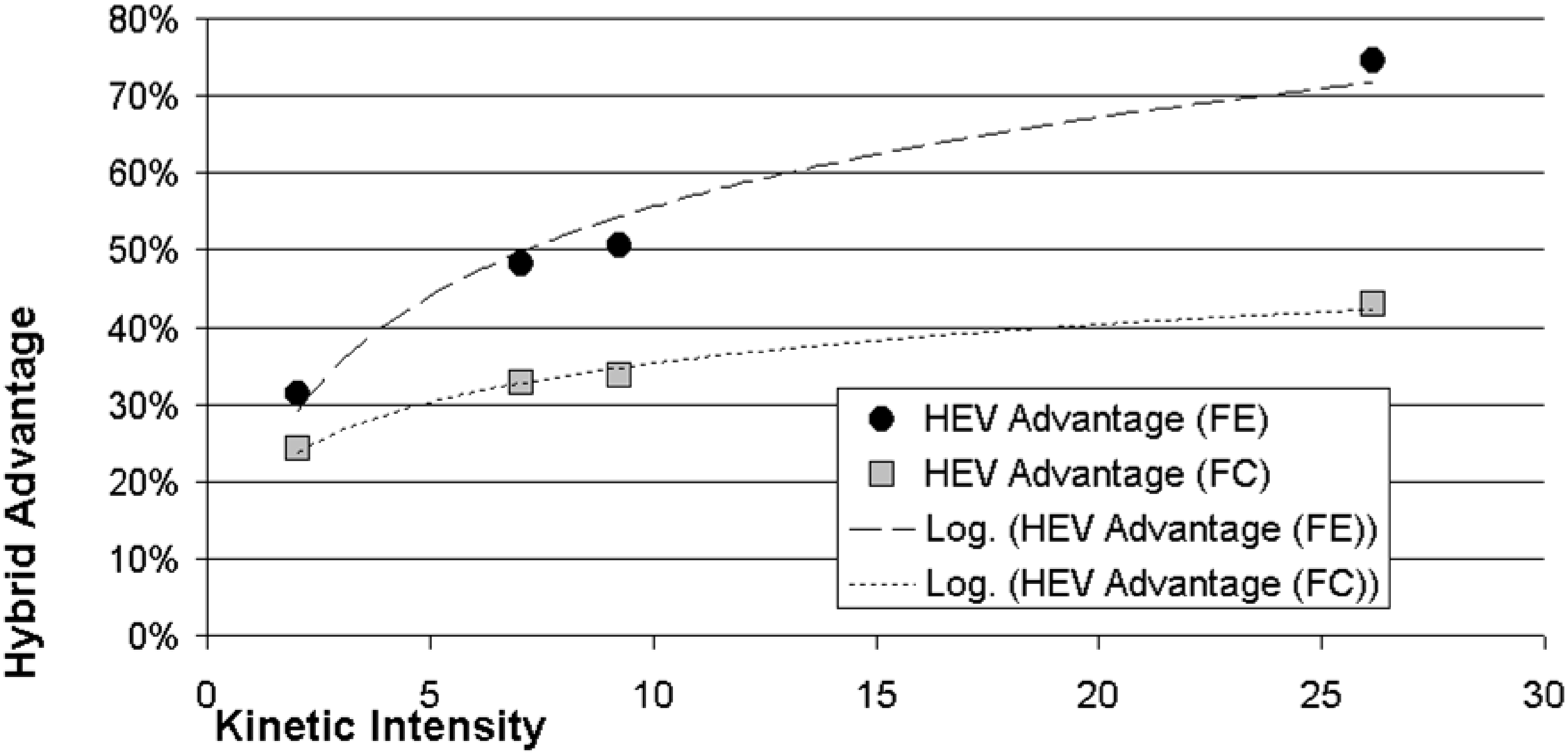
Example: If you justify based on emissions, consider cost per ton of NOx Reduction:



What else can you do with DC info?

If you know a few measured data points, you can now predict % improvement for other routes/duty cycles fall based on a few key metrics: <u>Be Smart With Your Testing</u>



- Kinetic Intensity is an attempt to provide a measure of acceleration in cycle

Doesn’t the industry study this already?

Some do - traditional attempts to determine appropriate duty cycle have included:

1) Using previously published data for a vocation (MAN, CILCC, OCTA, etc)
   - Not always accurate for specific location

2) Using limited or basic metrics like ‘stops per mile’ or ‘average speed’ based on overall fleet averages or ‘desired’ routes
   - Not specific to tell you enough

3) Measuring actual vehicles and large numbers or vehicles
   - Takes a long time to design and complete this process without a process or tool

There could be an easier way….

NREL and others have developed 'tools' for industry to utilize:

WVU: A tool that builds new driving cycles from standard cycles – Emissions Focus

Oak Ridge National Lab: A tool that can generate duty cycles based on data collected by ORNL.

NREL's Drive Cycle Tool: Created mainly for fuel economy analysis, it provides a simple, accessible method to help industry users easily capture *their* data, analyze it, create and compare it to fully understand what is happening in their own fleet:

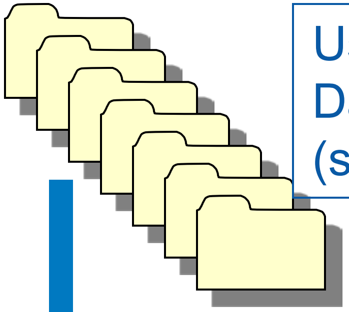
Tell Me What I Have in My Fleet!

1. **Method to help users generate and better understand *their* specific drive cycle (fleet wide, region or depot/local level)**
2. **Generate custom test cycles (~30 mins) from *their* large set of on-road experimental data.**
3. **Compare *their own* user supplied data to known and common industry test cycles – answers the question: what cycle should I use to evaluate this technology?**

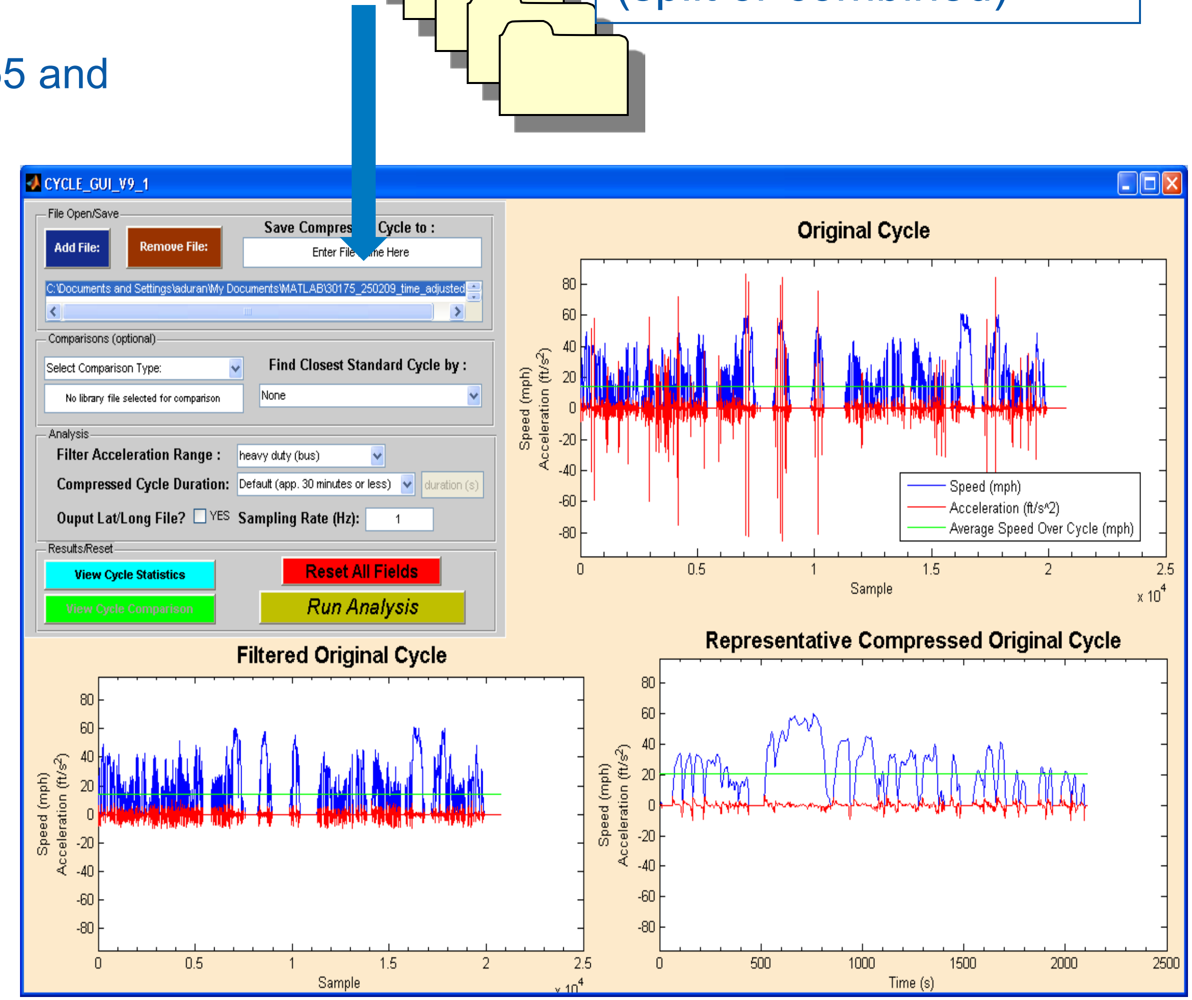
Specifics – What Does the NREL Tool Do?

1. It Provides for User Directed Analysis of User Supplied Data

- Extracts:
- Combines or Splits data:
- Filters: ~10 filters
- Calculates all known stats (55 and counting)



User Data: Multiple Days of Route Data (split or combined)



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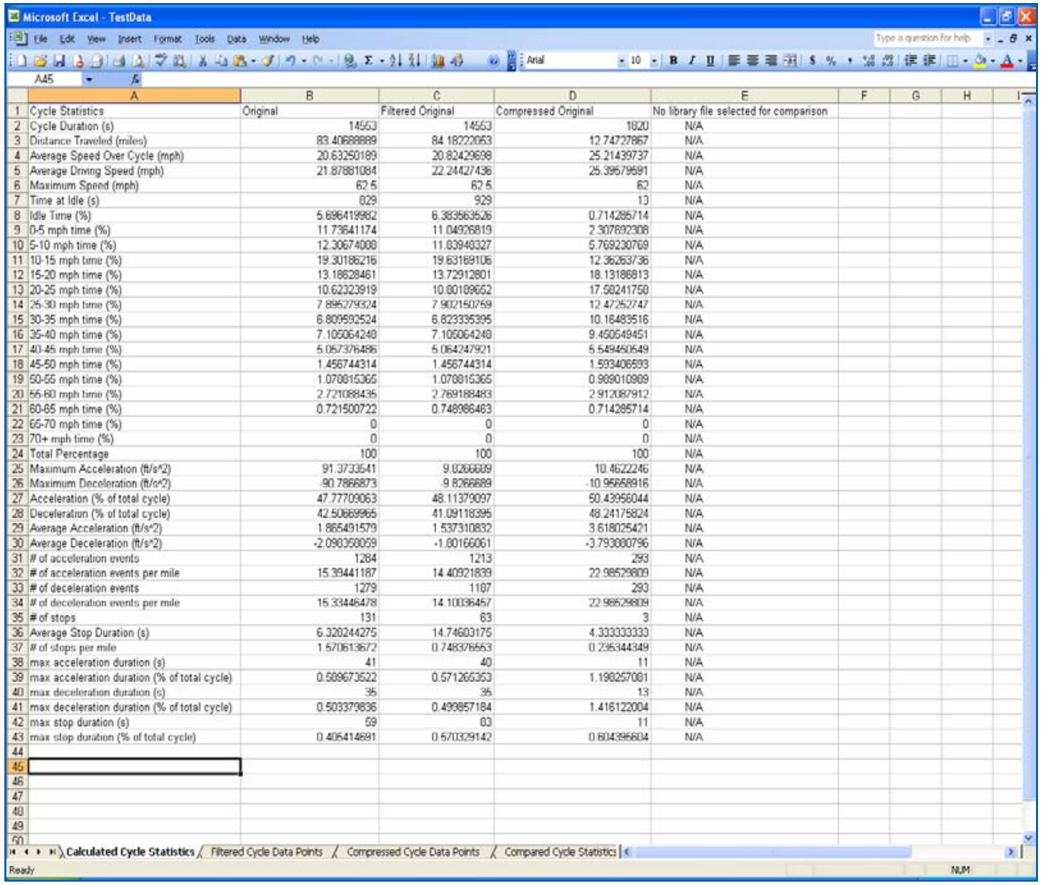


Cycle Statistics	Original	Filtered Original	Compressed Original	No library file selected for comparison
Cycle Duration (s)	14563	14563	1820	N/A
Distance Traveled (miles)	83.40688889	84.18222063	12.74727867	N/A
Average Speed Over Cycle (mph)	20.63250189	20.82429698	25.21439737	N/A
Average Driving Speed (mph)	21.87881084	22.24427436	25.39679691	N/A
Maximum Speed (mph)	62.5	62.5	62	N/A
Time at Idle (s)	829	929	13	N/A
Idle Time (%)	5.696419982	6.383563526	0.714285714	N/A
0-5 mph time (%)	11.73641174	11.04926819	2.307692308	N/A
5-10 mph time (%)	12.30674008	11.83948327	5.769230769	N/A
10-15 mph time (%)	19.30186216	19.63169106	12.36263736	N/A
15-20 mph time (%)	13.18628461	13.72912801	18.13186813	N/A
20-25 mph time (%)	10.62323919	10.80109652	17.58241758	N/A
25-30 mph time (%)	7.896279324	7.902150759	12.47252747	N/A
30-35 mph time (%)	6.809592524	6.823335395	10.16483516	N/A
35-40 mph time (%)	7.105064248	7.105064248	9.450549451	N/A
40-45 mph time (%)	5.067376486	5.064247921	5.549450549	N/A
45-50 mph time (%)	1.456744314	1.456744314	1.593406593	N/A
50-55 mph time (%)	1.070815365	1.070815365	0.909010989	N/A
55-60 mph time (%)	2.721088435	2.769188483	2.912087912	N/A
60-65 mph time (%)	0.721500722	0.748986463	0.714285714	N/A
65-70 mph time (%)	0	0	0	N/A
70+ mph time (%)	0	0	0	N/A
Total Percentage	100	100	100	N/A
Maximum Acceleration (ft/s^2)	91.3733541	9.8266689	10.4622246	N/A
Maximum Deceleration (ft/s^2)	-90.7866873	-9.8266689	-10.95658916	N/A
Acceleration (% of total cycle)	47.77709063	48.11379097	50.43956044	N/A
Deceleration (% of total cycle)	42.50669965	41.09118395	48.24175824	N/A
Average Acceleration (ft/s^2)	1.865491579	1.537310832	3.618025421	N/A
Average Deceleration (ft/s^2)	-2.090358059	-1.80166061	-3.793080796	N/A
# of acceleration events	1284	1213	293	N/A
# of acceleration events per mile	15.39441187	14.40921839	22.98529809	N/A
# of deceleration events	1279	1187	293	N/A
# of deceleration events per mile	15.33446478	14.10036457	22.98529809	N/A
# of stops	131	63	3	N/A
Average Stop Duration (s)	6.328244275	14.74603175	4.333333333	N/A
# of stops per mile	1.570613672	0.748376653	0.235344349	N/A
max acceleration duration (s)	41	40	11	N/A
max acceleration duration (% of total cycle)	0.589673522	0.571265353	1.198257081	N/A
max deceleration duration (s)	35	35	13	N/A
max deceleration duration (% of total cycle)	0.503379836	0.499857184	1.416122004	N/A
max stop duration (s)	59	83	11	N/A
max stop duration (% of total cycle)	0.405414691	0.570329142	0.604395604	N/A

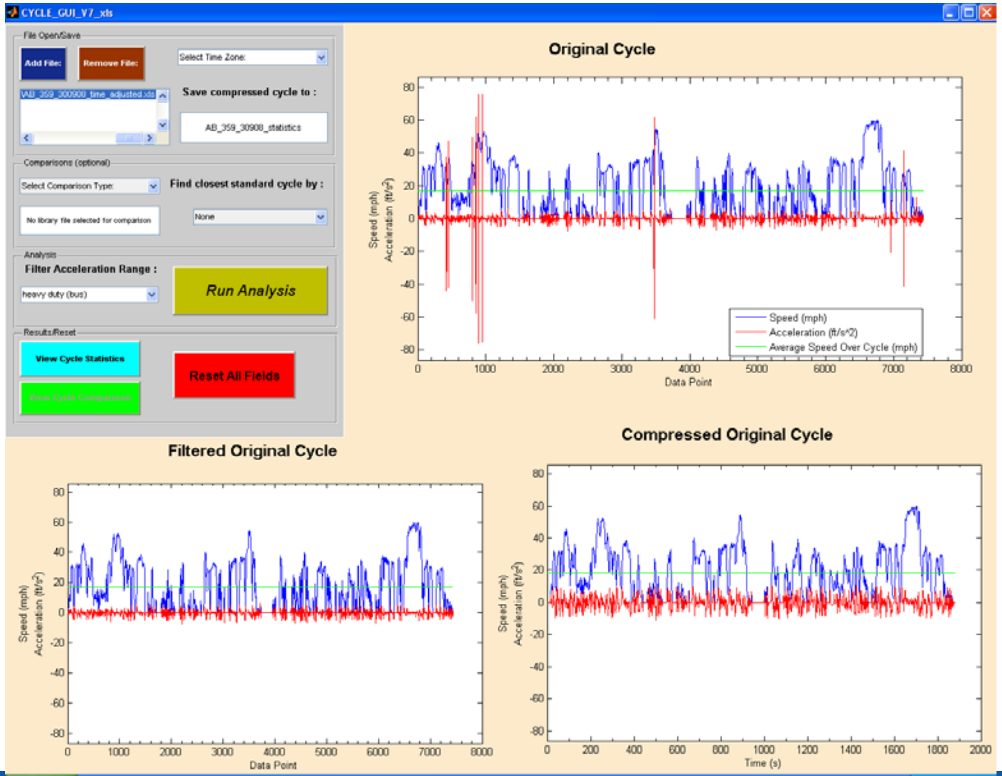
Quickly processes and analyzes data in a consistent manner

Specifics – What Does the NREL Tool Do?

2. Cycle Generation – matches fuel economy

- Crunch any amount of user supplied data and output a user cycle (speed vs. time) for dynamometer testing or modeling based on raw data inputted
- Goal = creates a short, statistically representative cycle (within 5% accuracy statistically and fuel economy) for dyno testing or modeling
- We've validated to show same mpg for short or long cycle within 5%

Original Data (~8000 seconds)

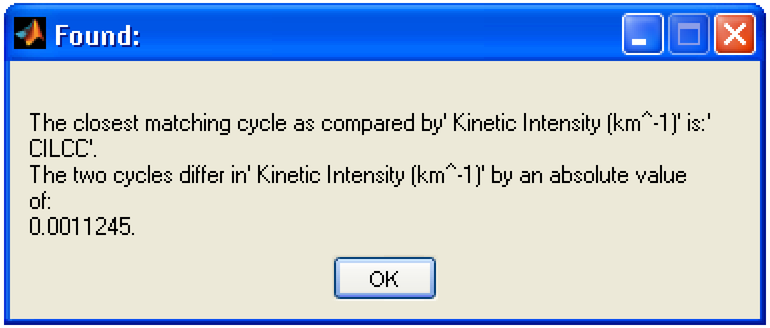


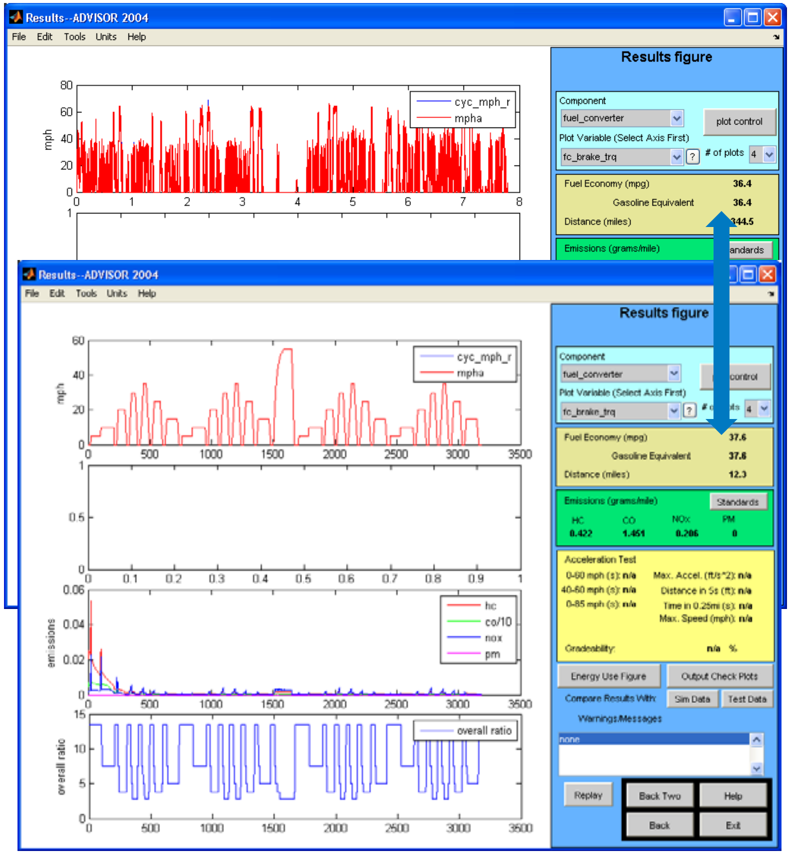
Filtered and Shortened Data (~1800 seconds)

Specifics – What Does the NREL Tool Do?

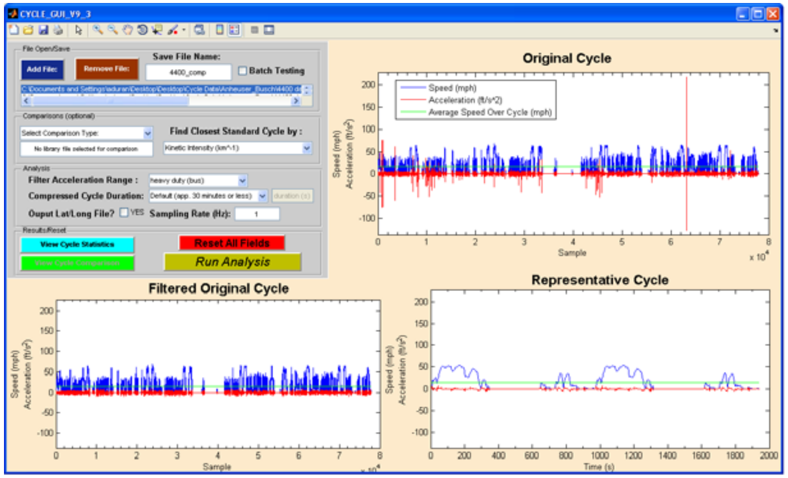
3. Compare and Select Best Available Industry Cycle

- Matched based on user selected statistics (mph, stops per mile, kinetic intensity, etc). This will tell the user the best cycle to quantify MPG. Original data vs 'best selected' data showed modeled mpg results within 3%





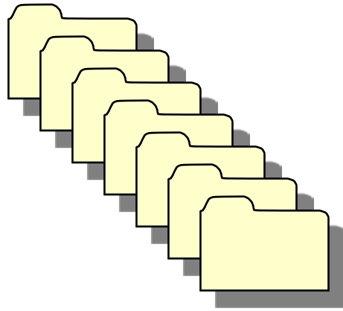
Multiple metric selection criteria for 'best match'



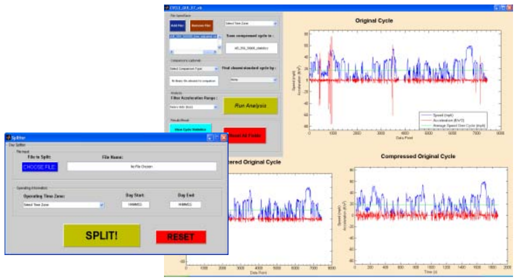
Original data to compressed

Summary

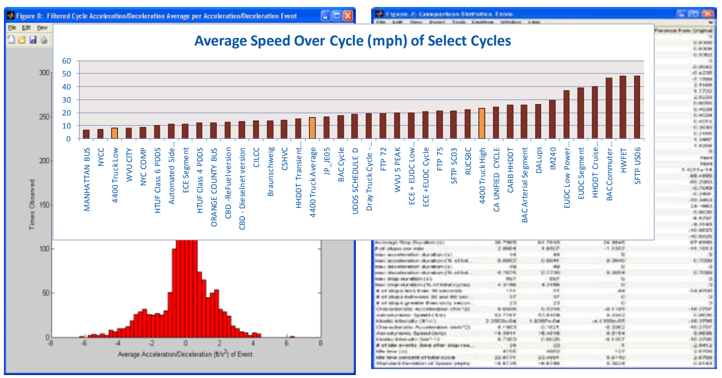
Simple GPS loggers to acquire data



set of daily GPS route data

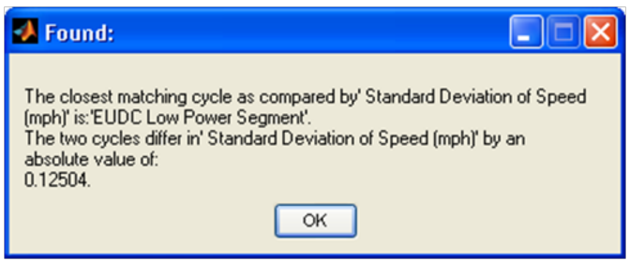


Tool filters and sorts data in desired set

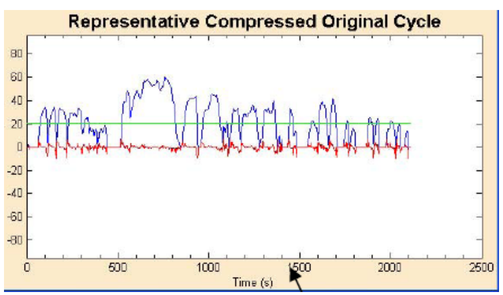


Full understanding of supplied data: daily variation info, stats for original, filtered and shortened data

cycles with similar mpg



Closest 'Standard' Cycle Match



User Specific Test Cycle Generated

Future – Tool Moving Forward

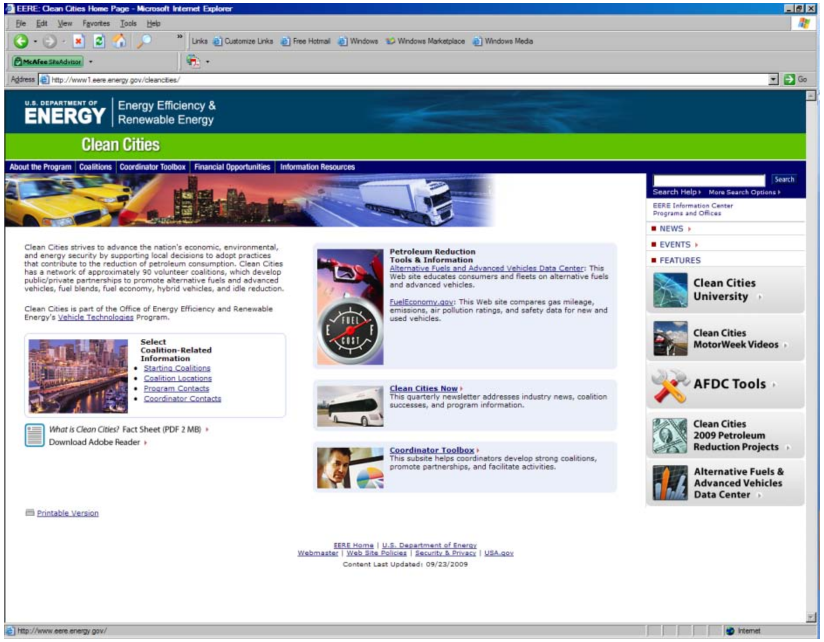
1. **DOE Clean Cities / NREL will be implement a web based version of tool and make this available to the general public**
   - Allow users (fleets or individuals) to upload their own data, generate a custom drive cycle that represents their daily driving habits, and finds 'best fit' standard cycle –
   - useful to see if 'actual' driving does not match the industry standard test cycle
   - Will be user-friendly and 'secure'

2. **Improve Visualization and interaction capabilities**

   - Graphically select individual sections of source data from which to generate test cycles

3. **Modify tool to analyze duty cycle characteristics for other parameters (battery duty cycle, temperatures, etc)**

4. **Tie this tool and others into accessible data bases for industry to utilize**



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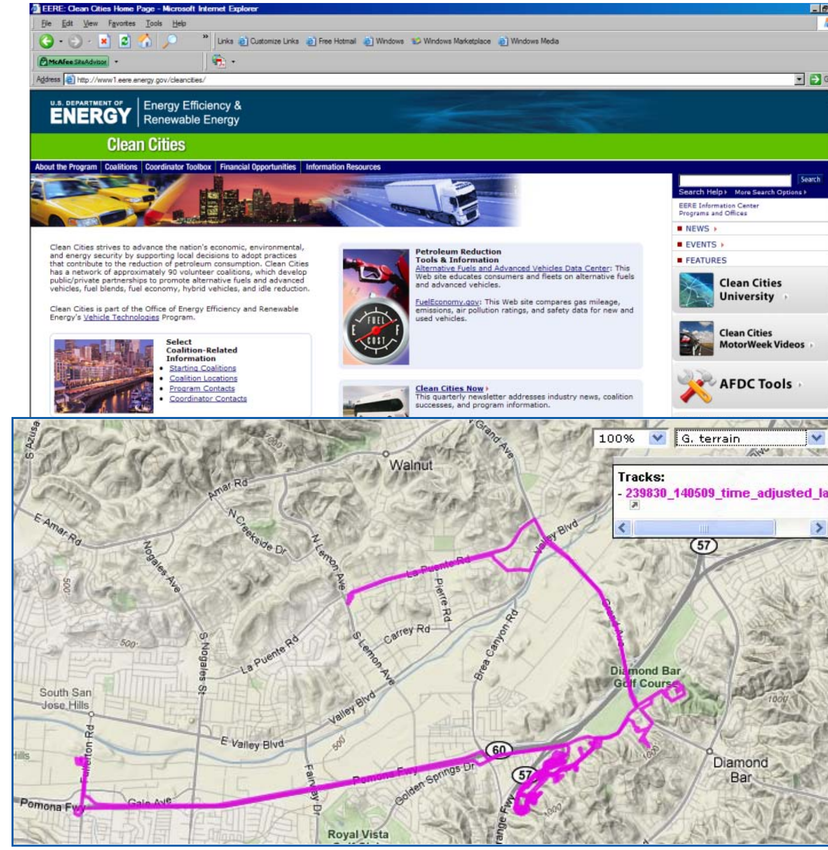

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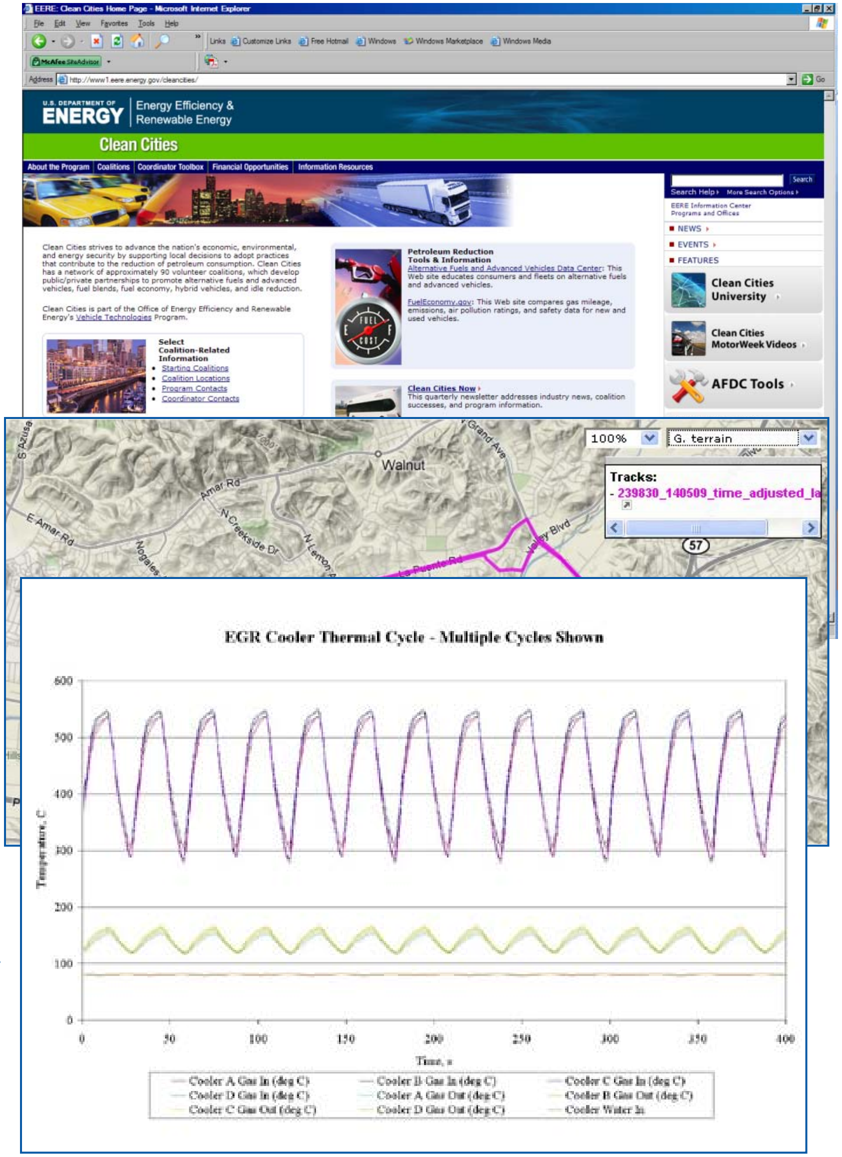

Thank You!

Take Aways:

1. <u>Duty Cycle Matters </u>– has a large effect on fuel economy
2. Easy to Use, Fleet Focused Tool Now Available For Use to More Fully Understand This

- **For More Info:**
  - **NREL Tool and NREL Fleet Activities:**

    - Kevin Walkowicz – NREL's Advanced Vehicle Testing Activity
    - Kevin.walkowicz@nrel.gov
    - 303-275-4492

- **Acknowledgements:**
  - **Work Funded by DOE's Vehicle Technologies Program:**
    - Lee Slezak – Advanced Vehicle Program Manager for Vehicle and Systems Simulation and Testing

Additional Information

WVU Tool Info: An interactrive design tool has been developed in Matlab that allows building new driving cycles through the concatenation of individual microtrips obtained by segmentation of second by second measurements from standard cycles. The generated new cycles have prescribed characteristics in terms of relevant parameters such as average speed, stops per mile, percentage idle, speed standard deviation, and kinetic intensity. The selection of microtrips to achieve the desired cycle characteristics is performed using a customized genetic algorithm. The generated cycles are used to increase the available database for regression-based modeling of fuel efficiency and emissions of CO_2, CO, NOx, HC, and PM. The validation of the approach is currently in process at WVU.

Tu J., Wayne W. S., Perhinschi M. G., "Correlation Analysis of Duty Cycle Effects on Exhaust Emissions and Fuel Economy", submitted to the Journal of the Transportation Research Forum, January 2009

Tu J., Perhinschi M. G., Wayne W. S., Marlowe C., Tamayo S., Clark, N. N., "Development of Duty Cycle Generator Based on Genetic Algorithm for Emissions and Fuel Economy Modeling", 19th Coordinating Research Council (CRC) On-Road Vehicle Emissions Workshop, Poster Session, March 23-25, 2009, Hyatt Regency Mission Bay, San Diego, CA

Marlowe C., "Development of Computational Tools for Modeling Engine Fuel Economy and Emissions", MS Thesis in Mechanical Engineering, Department of Mechanical and Aerospace Engineering, West Virginia University, 2009

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ORNL Tool Info: "The Oak Ridge National Laboratory has developed a Duty Cycle Generation Tool (DCGenT) that can generate duty cycles of user specified duration and user specified characteristics (e.g., metro/urban/rural, good/poor weather conditions, road grade, etc.) based on data collected from real-world driving environments. The data base for Class-8 long-haul operations contains more than 750,000 miles of driving data. Contact Bill Knee 865.946.1300, kneehe@ornl.gov for additional information, and download the Class-8 Final Report that discusses the data collection effort, the collected data and the duty cycle generation tool from: http://cta.ornl.gov/cta/Publications/Reports/ORNL_TM_2008-122.pdf. ORNL is currently engaged in collecting medium truck performance data on two-of four vocations in the Class-6/-7 domain."

Bill Knee 865.946.1300, kneehe@ornl.gov