Post-Combustion Efficiency Opportunities and Challenges

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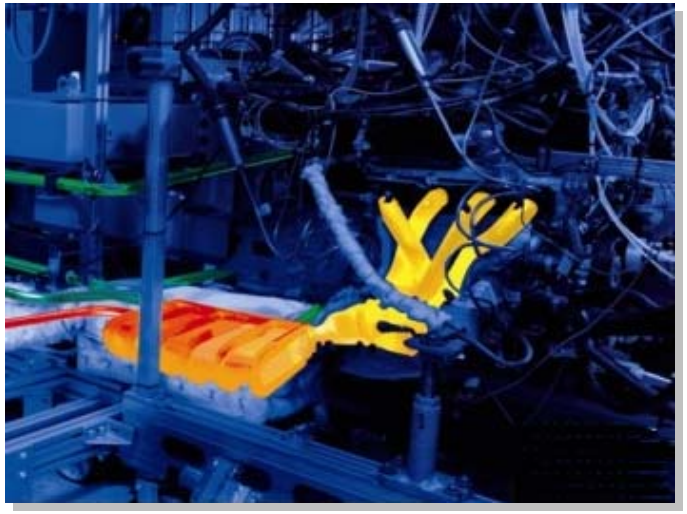
U.S. DEPARTMENT OF ENERGY

With less than ½ of fuel energy converted to useful work, substantial efficiency improvements will require a reduction in losses to the environment

Fuel In



Heat Loss

Exhaust

Power

Image Source A. Obieglo et al., "Future Efficiency Dynamics with Heat Recovery", BMW Group, 2009 DEER Conference

Issues to consider with respect to energy recovery:

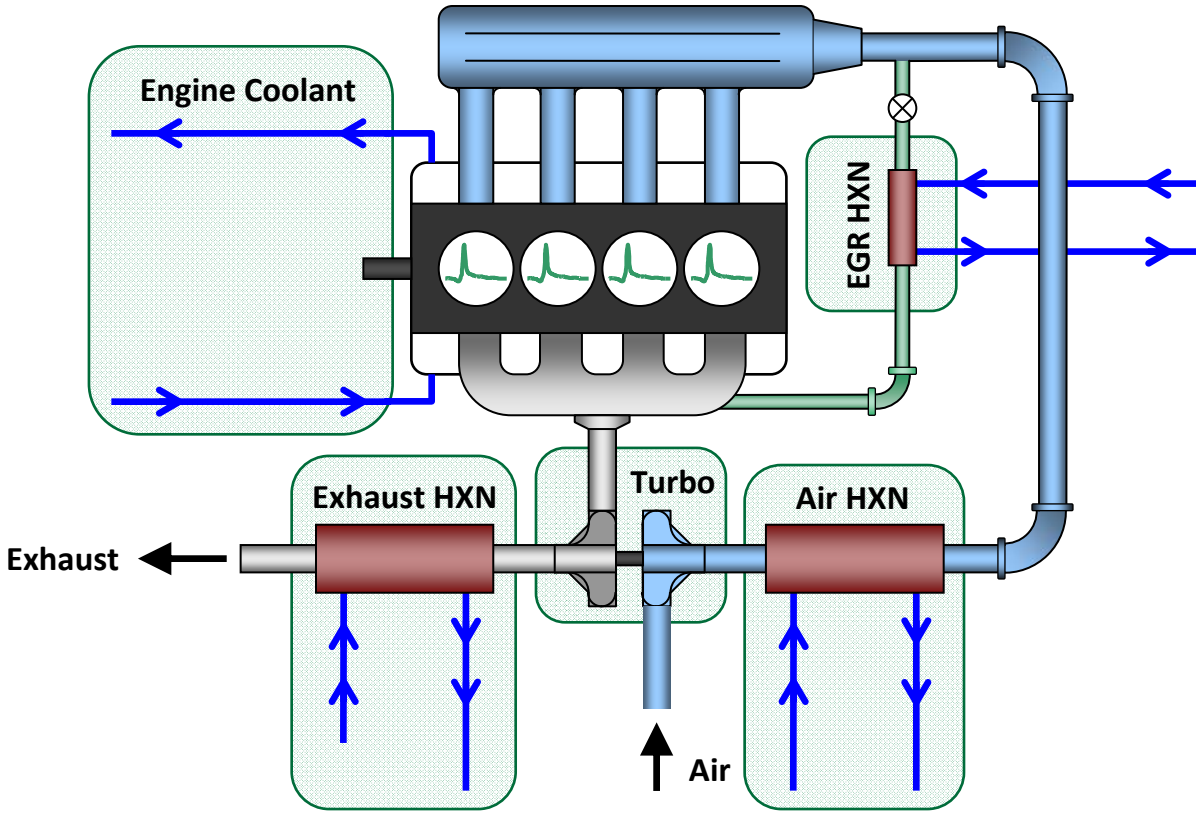
- **Source and quality.**
- **Recovery method.**
- **Integration and drive-cycle matching.**
- **Material needs.**

Discussion topics for this talk.

Structure

- ➡ **Source and quality.**
- Recovery method.
- Integration and drive-cycle matching.
- Material needs.
- Take away points.

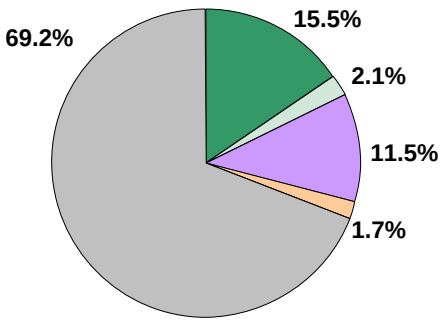
Numerous sources of heat rejection to environment



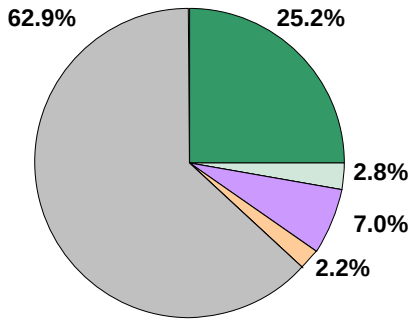
Energy quality is much different for the different sources.

Example experimental Availability distributions from a GM 1.9-L diesel engine for conditions consistent with a LD drive cycle

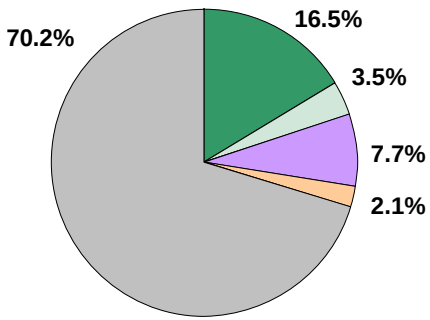
Catalyst transition temperature
1500 rpm, 1.0 bar



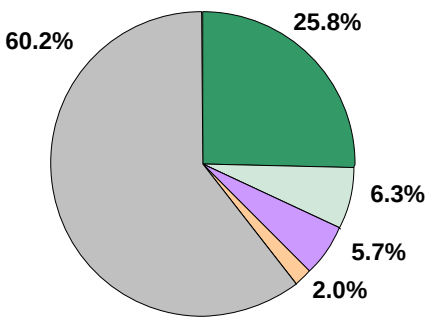
Low speed cruise
1500 rpm, 2.6 bar



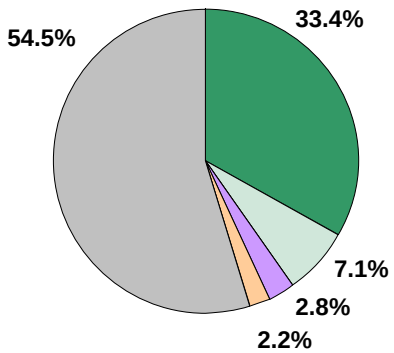
Low speed with acceleration
2000 rpm, 2.0 bar



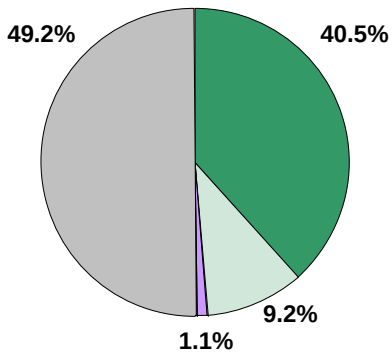
Moderate acceleration
2300 rpm, 4.2 bar



Hard acceleration
2600 rpm, 8.8 bar



Peak brake thermal efficiency
2250 rpm, 18 bar



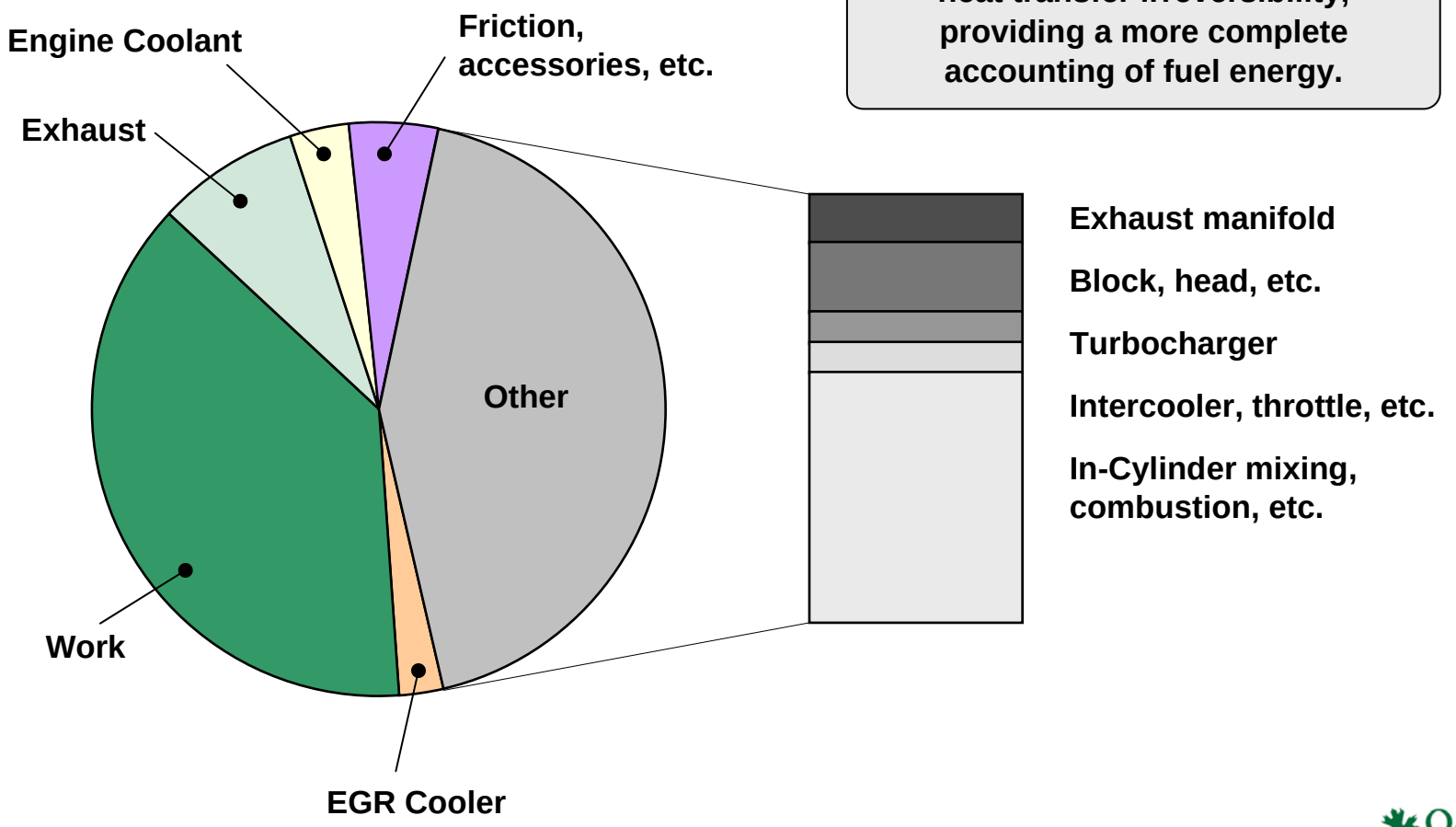
Fraction of Fuel Availability

- Brake Work
- Friction
- Exhaust
- EGR Cooler
- Other (Heat loss, combustion irreversibility, etc.)

System modeling provides further insight into opportunities which may be difficult or impossible to measure on-engine

Significant portion of fuel availability is difficult to account for with experimental measurements.

Simulation adds missing details related to combustion, mixing, and heat transfer irreversibility, providing a more complete accounting of fuel energy.



Structure

- Source and quality.
- ➡ **Recovery method.**
- Integration and drive-cycle matching.
- Material needs.
- Take away points.

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Numerous factors to consider in selecting thermal recovery method

- **Recovery system efficiency.**
- **Drive-cycle matching (*i.e.*, transient response).**
- **Ease of system integration.**
- **Return on investment (ROI).**

Technology	Efficiency	Response	Integration	ROI
Thermoelectric Conversion	+	+++	+++	+
Brayton bottoming cycle	++	++	++	++
Rankine bottoming cycle	+++	+	+	++
Turbo-compounding	++	+++	+++	+++

Recent progress in thermal energy recovery

- **Bottoming Cycles**
  - » Cummins demonstrated 7% BTE improvement on HD application.
  - » BMW demonstrated 10% increase in “engine performance” for LD application.
  - » ORNL demonstrated 7% BTE improvement in peak BTE for LD application (4 kW from exhaust).
- **Thermoelectric Generators**
  - » Michigan State expect as much as 14% improvement in BTE.
  - » GM anticipates 1 mpg improvement in Suburban (300-600 W of additional power).
  - » Materials appear to be major challenge.
- **Turbo-Compounding**
  - » Fluid and electrically coupled systems have been demonstrated on-engine.
  - » Combined turbo/super-charging potential reduces turbo-lag.

Structure

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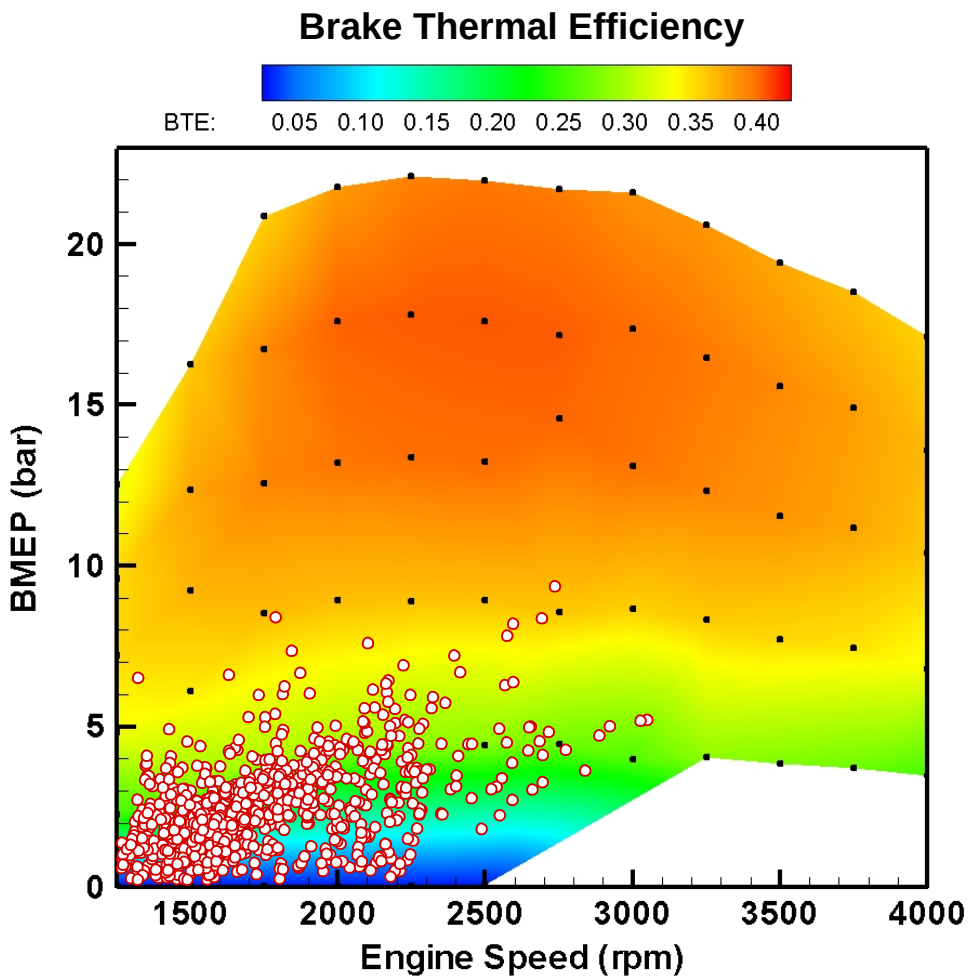
Engine drive cycles often do not match well with high engine efficiency

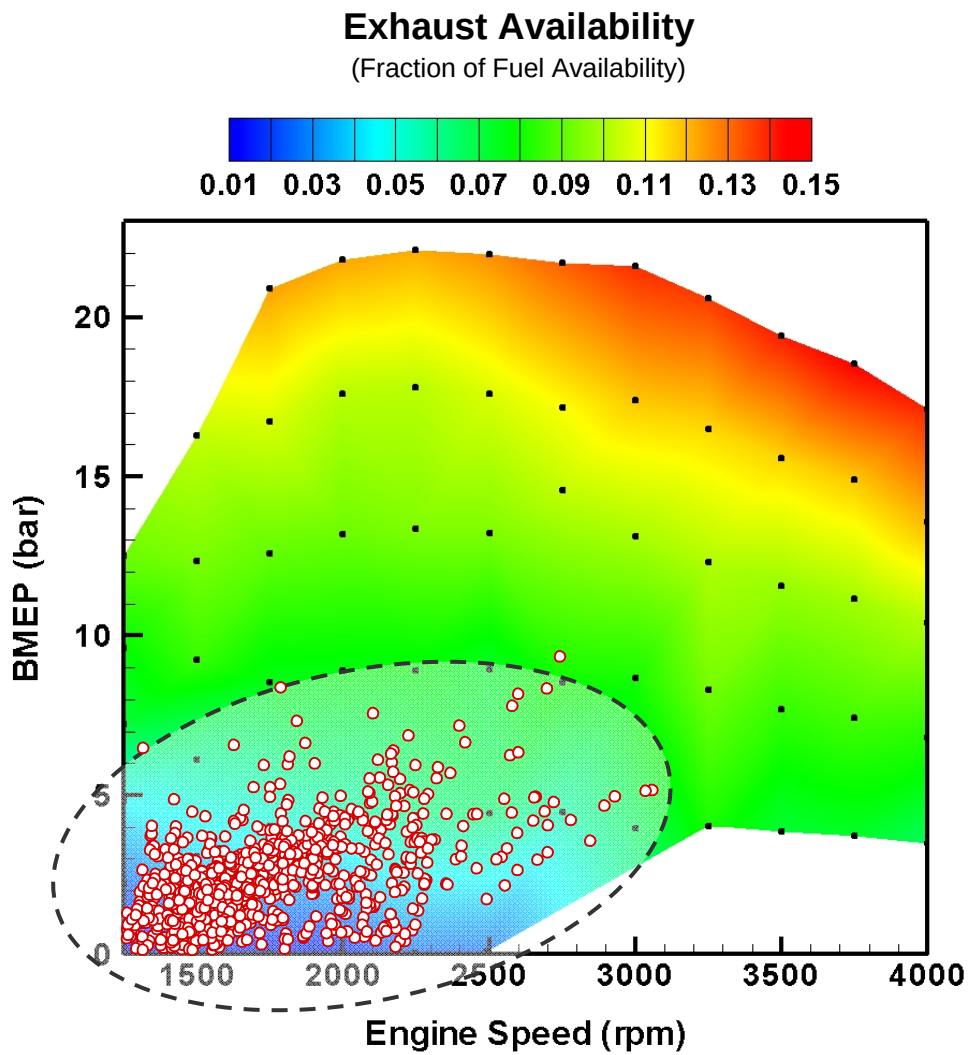
- **Example for light-duty diesel engine.**
- **High BTE operation in range 15 to 20 bar BMEP.**
- **UDDS cycle corresponds to low efficiency engine conditions.**

Are there thermal energy recovery opportunities for these conditions?



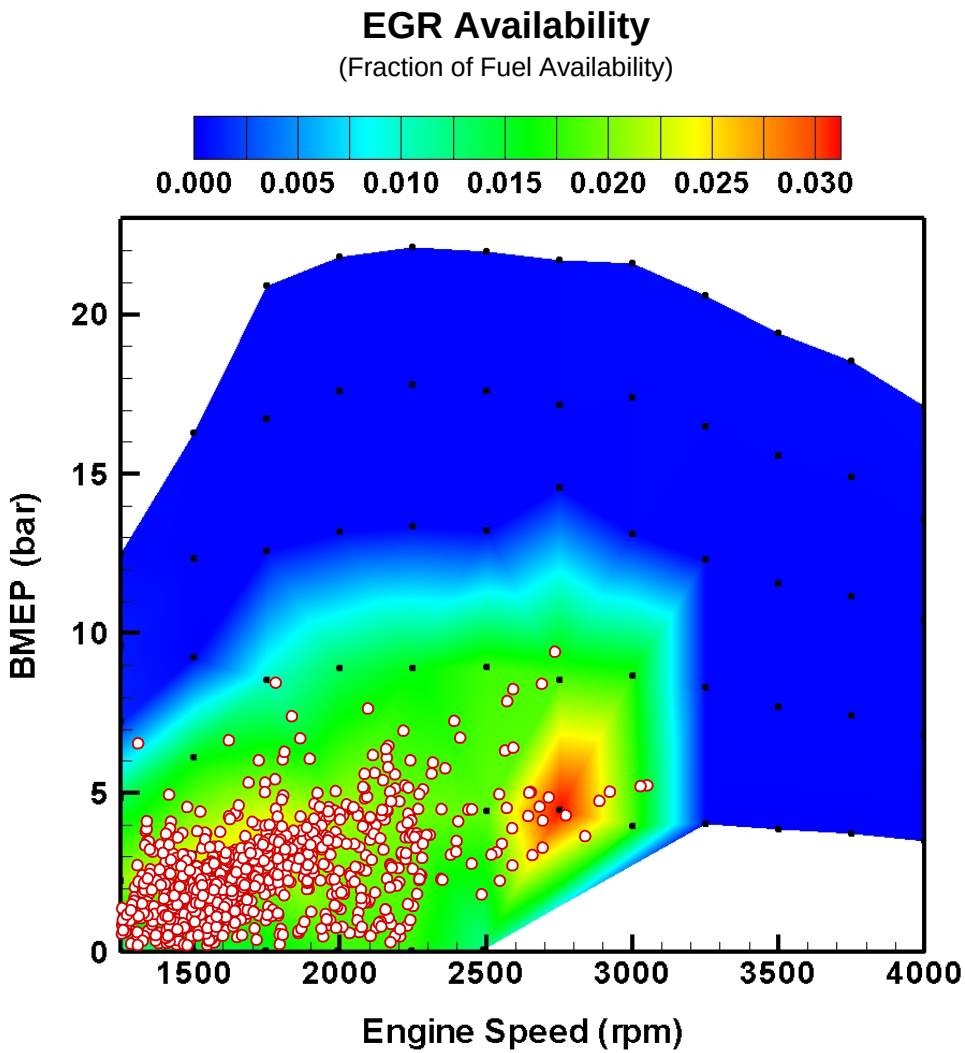
Significant energy discarded to the environment, particularly under high BMEP conditions

- **Exhaust energy quality is low for much of the UDDS cycle.**
- **Down-sizing is a better match for exhaust energy recovery.**
- **Transients (scatter in data) are also a major challenge.**



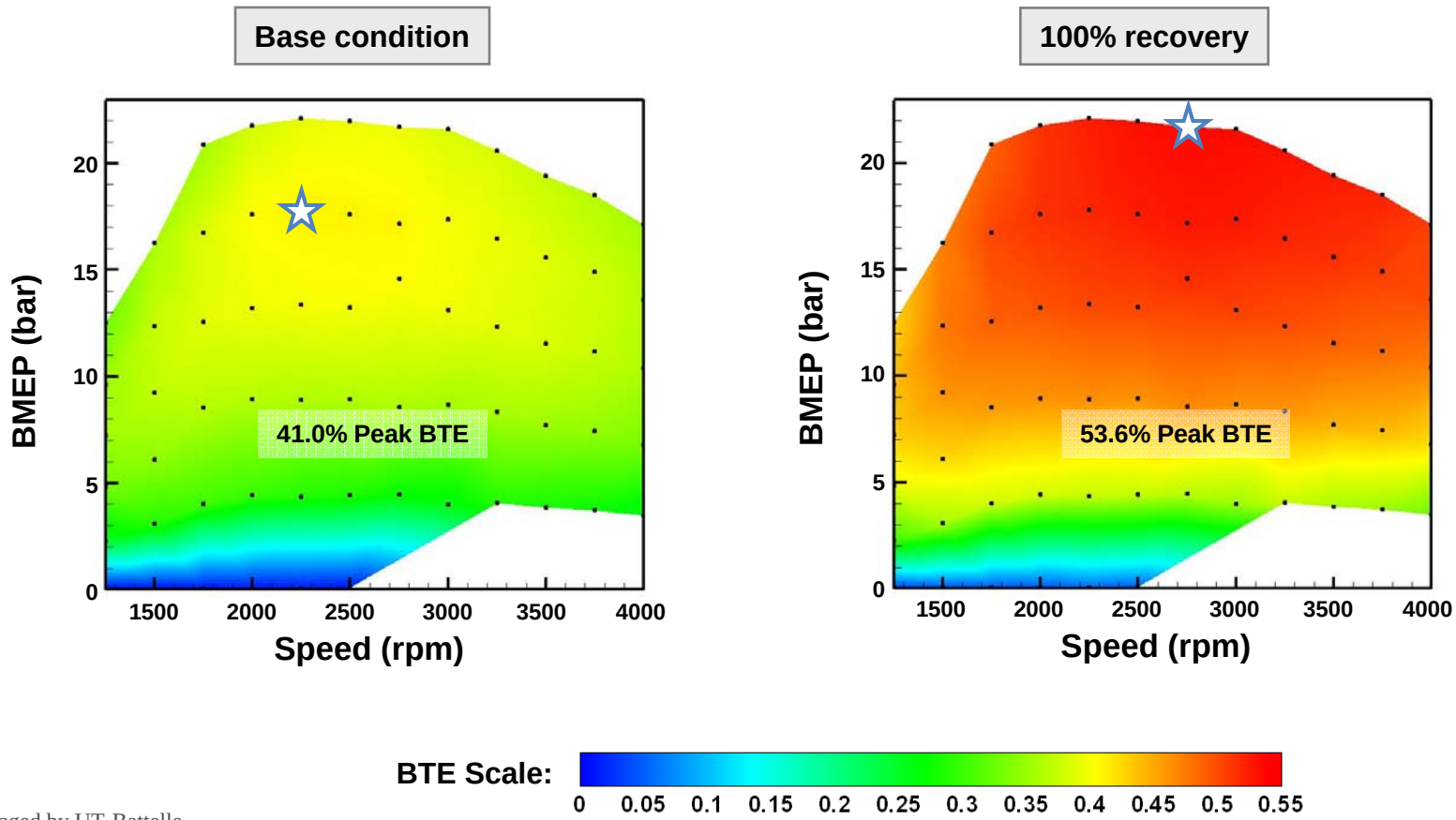
For low BMEP operation a non-negligible fraction of fuel energy is rejected through the EGR system

- **EGR Availability well matched with LD drive schedule.**
- **May be better match for LTC modes with high levels of dilution.**
- **Again, transients will be an issue for thermal energy recovery.**



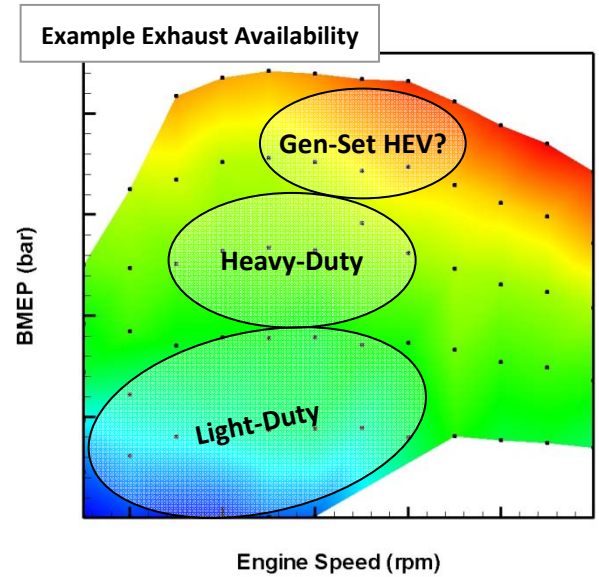
Combined engine-system efficiency shifts with thermal energy recovery

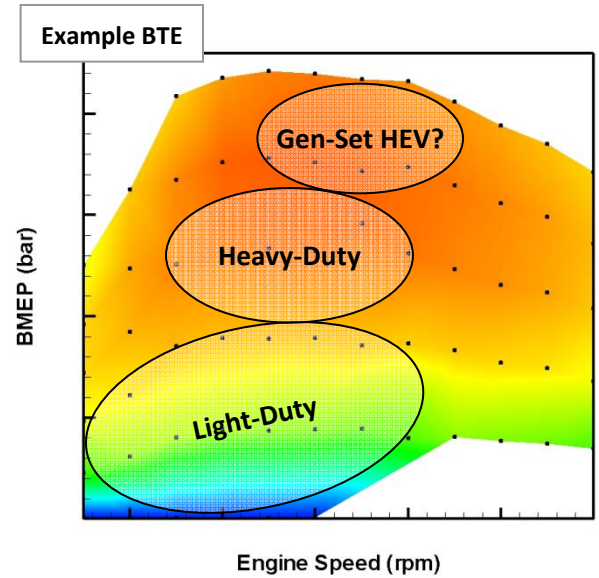
- **Engine-system efficiency estimates based on 2nd Law availability from exhaust and EGR systems.**
- **Energy recovery efficiency assumed fixed across the speed-load range to simplify estimates.**



Vehicle drive-cycle extremely important in effective recovery of thermal energy

- **LD drive schedule not well suited for most recovery methods.**
  - » Highly transient operation causes thermal time constant mismatch between engine and recovery system.
  - » Low Availability for majority of the drive schedule.
  - » Turbo-compounding probably most promising solution.
- **HD drive schedule better suited due to higher BMEP operation.**
  - » Less transient than LD drive schedule.
  - » High Availability of exhaust energy.
  - » Well suited for most forms of thermal energy recovery.
- **Generator set approach to HEV/PHEV best match for energy recovery.**
  - » Constant high-load, peak BTE operation.
  - » Start/stop operation potential problem. Control will be different than for conventional HEV/PHEV.
  - » Well suited for most forms of thermal energy recovery.





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- ➡ **Material needs.**
- Take away points.

Materials development critical to efficiency, weight, and implementation

- **Efficiency**
  - » Thermal insulation to focus heat rejection for maximum Availability.
  - » Improved heat transfer of system components (e.g., heat exchangers).
  - » Better thermoelectric materials.
- **Weight**
  - » Reduce impact on vehicle weight and corresponding drive-cycle efficiency.
- **Implementation**
  - » Minimize engine and recovery device thermal mismatch through thermal dampers and/or capacitors.
  - » Smaller, more effective heat exchangers.
  - » Power storage and transfer.

Take Away Points

- **Vehicle drive-cycle is critical to success of thermal energy recovery.**
- **Engine and thermal recovery systems must be optimized as a package.**
- **Focusing heat rejection to exhaust increases Availability and recovery potential of waste energy.**
- **New materials for thermal damping and storage will be important for maximizing thermal energy recovery across transient drive-cycles.**