Automotive Applications of High Efficiency Thermoelectrics.

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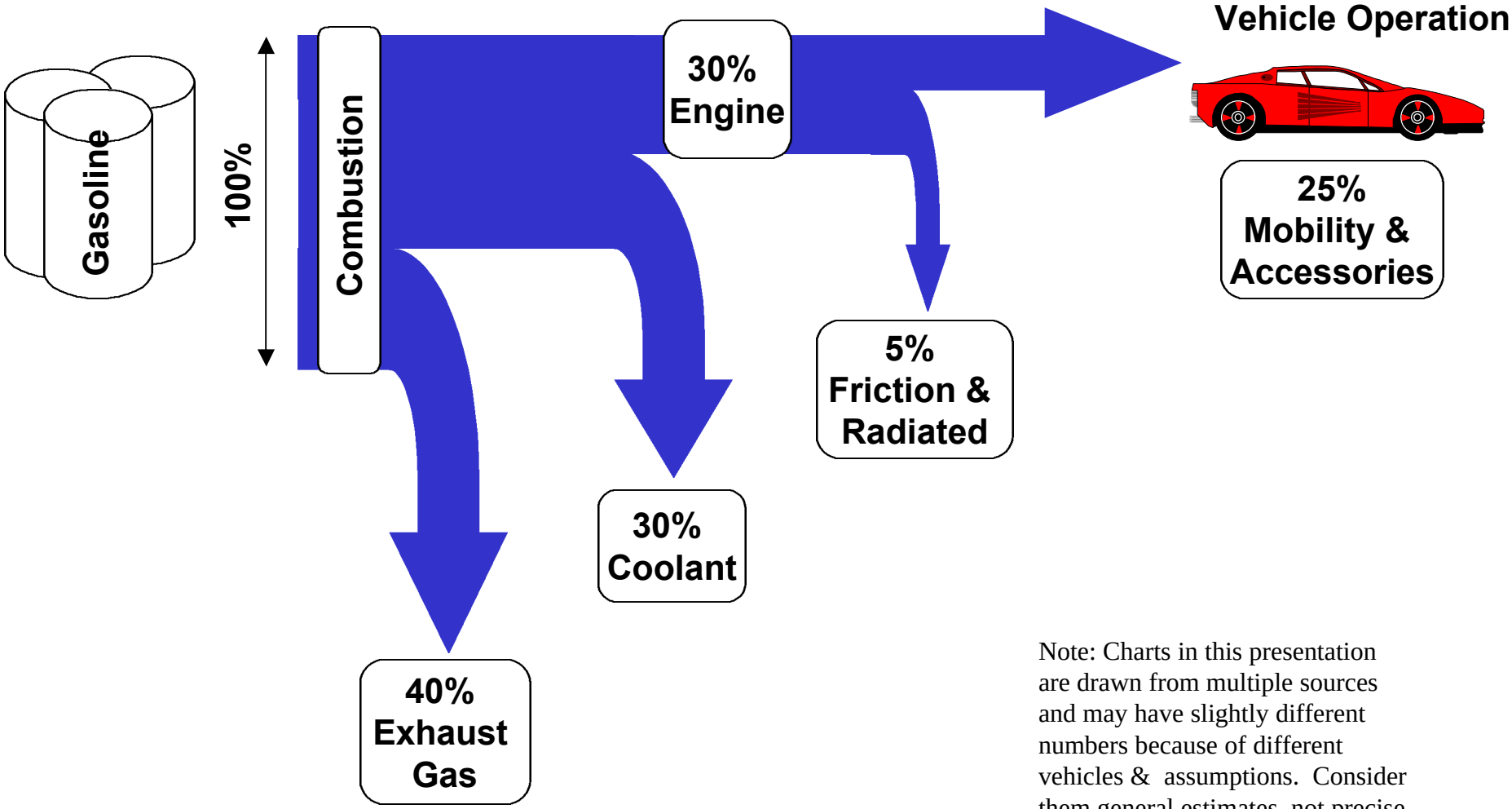
Automotive Thermoelectric Applications

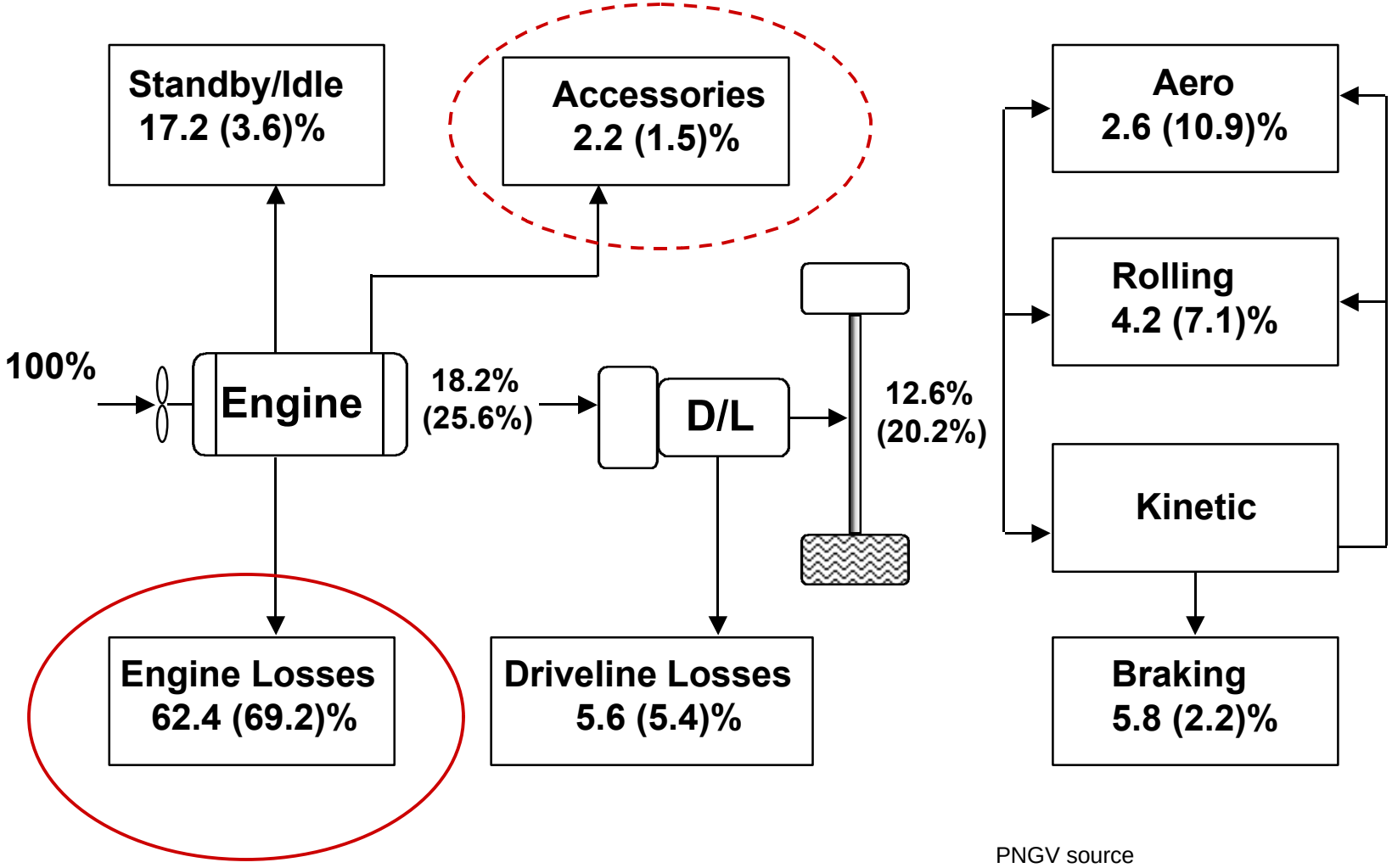
- Power Generation
- Cooling & Heating
- Concerns & Issues

Typical Energy Path In Gasoline Fueled Internal Combustion Engine Vehicle



Note: Charts in this presentation are drawn from multiple sources and may have slightly different numbers because of different vehicles & assumptions. Consider them general estimates, not precise analysis.

Energy Distribution - Typical Mid-Size Vehicle on Federal Test Procedure (FTP) - Urban (Highway) % energy use

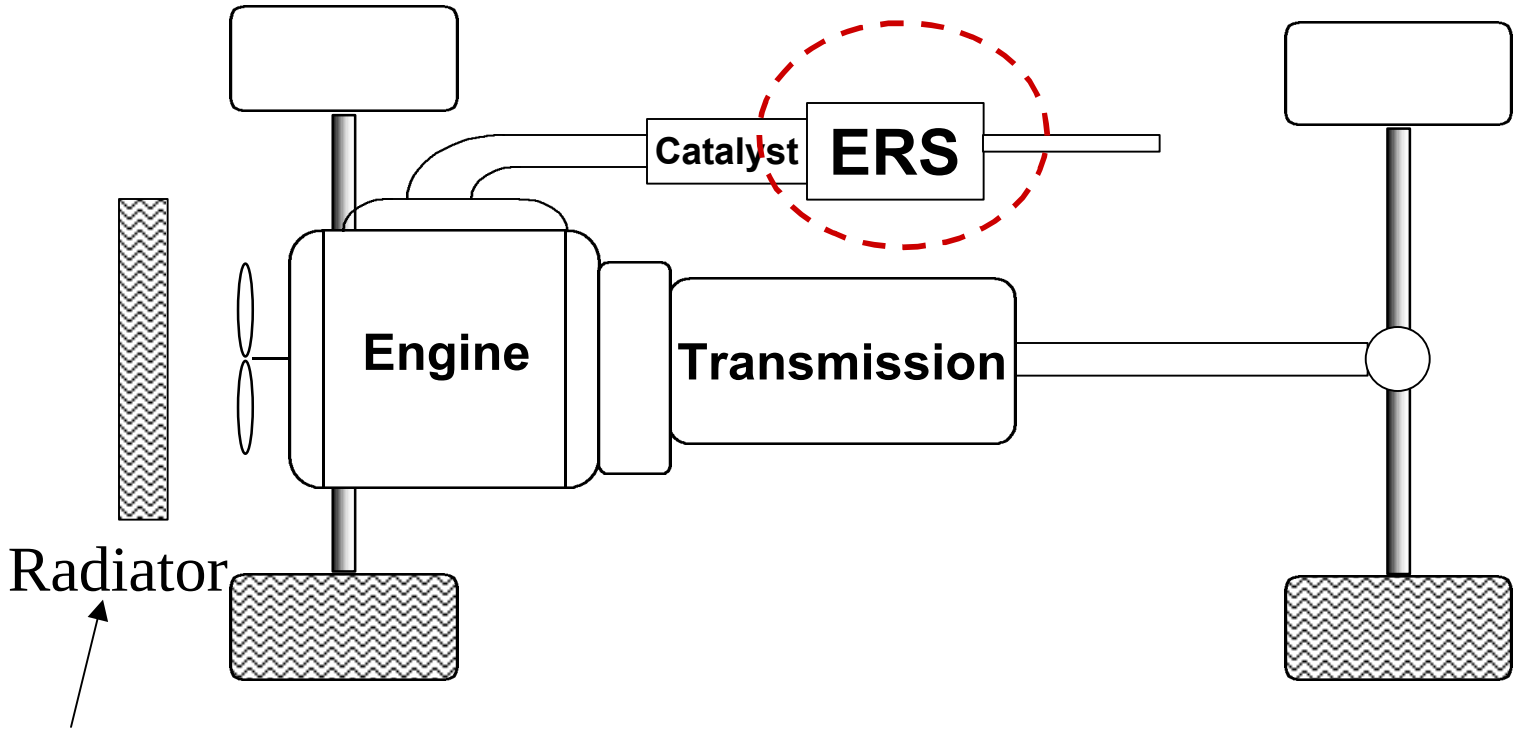


PNGV source

Automotive Thermoelectric Applications

- Power Generation
  - Electric power from exhaust or coolant energy to supplement or replace the conventional generator system
    - Conventional electrical requirements
    - Additional electrical loads
    - Supplement engine power for mobility
  - Potential fuel fired APU application
    - Allows engine off operation
  - Low power generator for wireless sensors
  - Solar power system
    - Example: Electric fans for cooling a parked vehicle

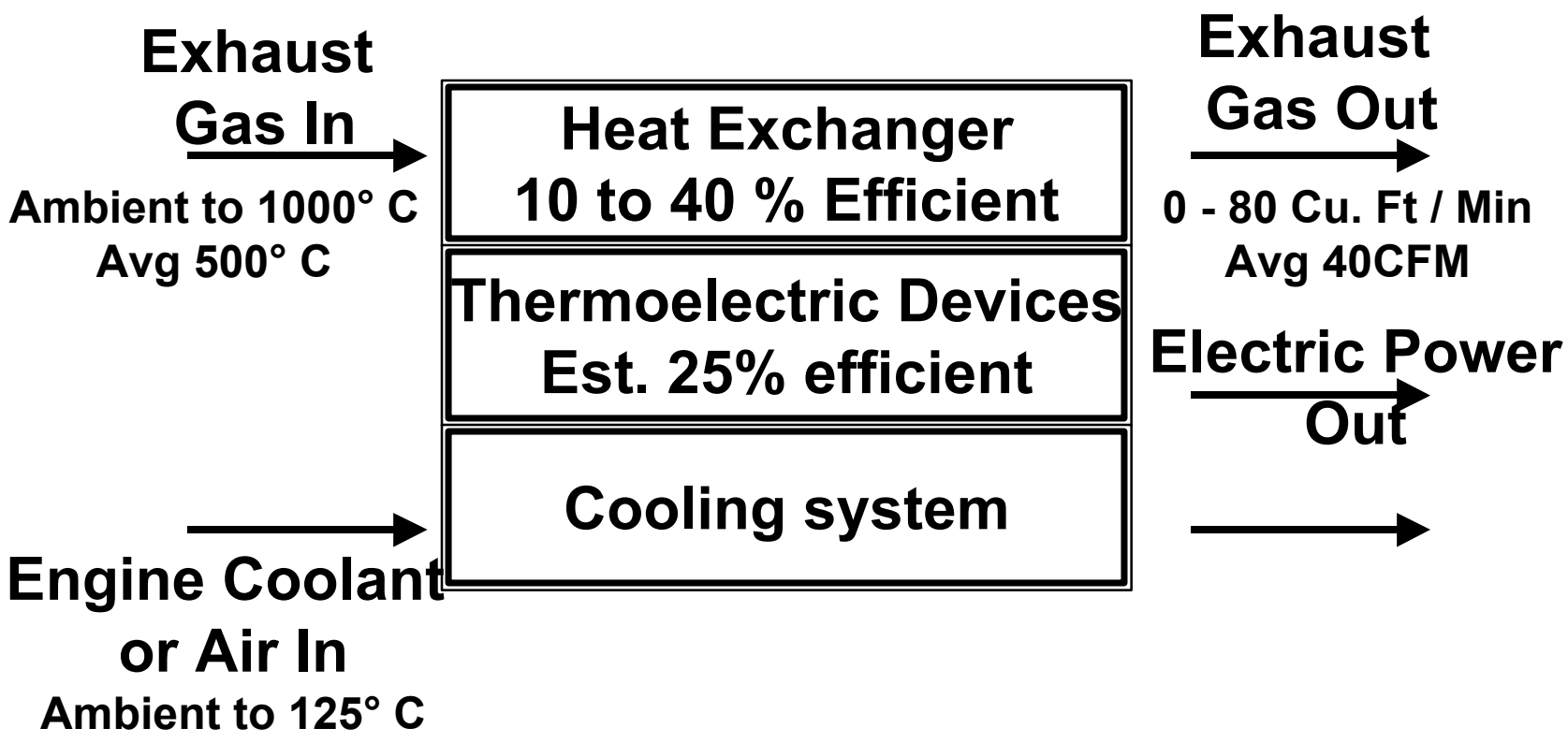
Example of an Energy Recovery System



Alternate: make the radiator into an energy recovery device. (Small delta T)

PNGV source

Example of an Energy Recovery System



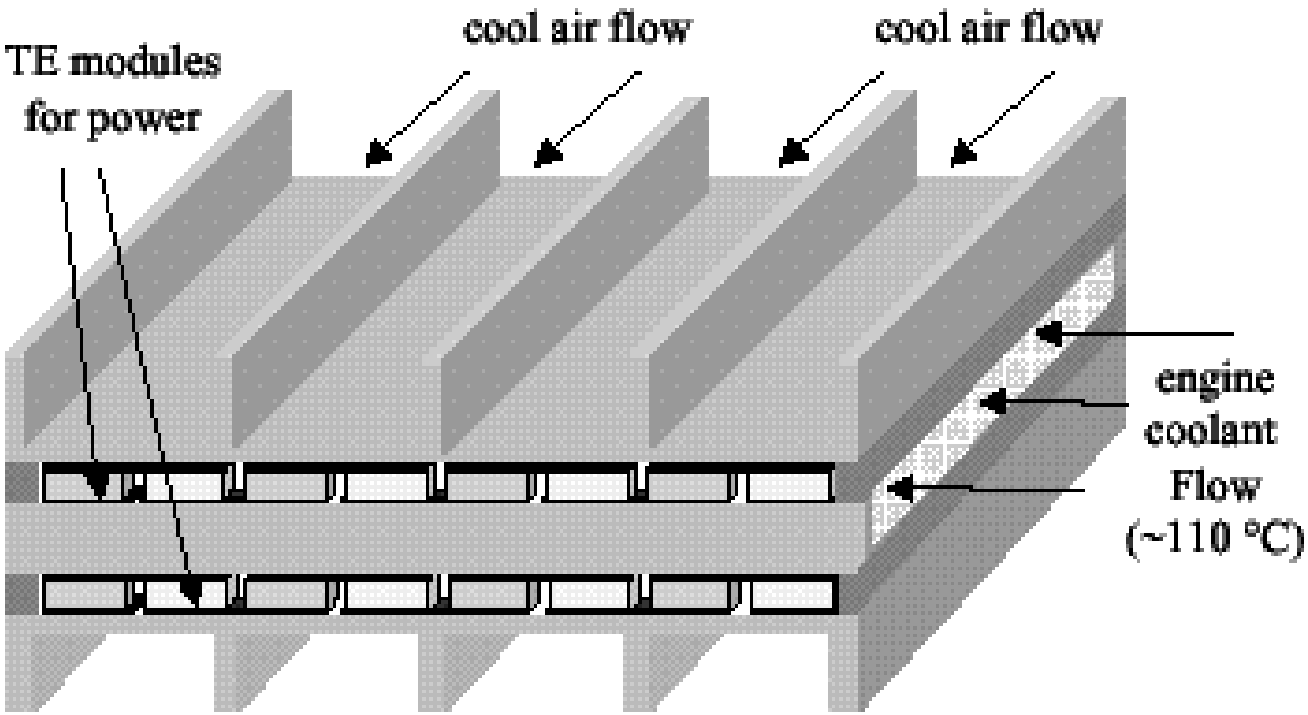
SAE TECHNICAL PAPER 2001-01-1021

Towards Optimization of Automotive Waste Heat Recovery Using Thermoelectrics

Douglas Crane, Gregory Jackson and David Holloway
University of Maryland, College Park

Conclusion: … The potential for a thermoelectric radiator to provide 1-2 kW (typical of current day alternators) over a range of engine operating conditions is still being investigated, but preliminary studies presented here suggest that even at low (engine) loads down to 25%, electrical power demands can be met…..

Example of a radiator thermoelectric generator design

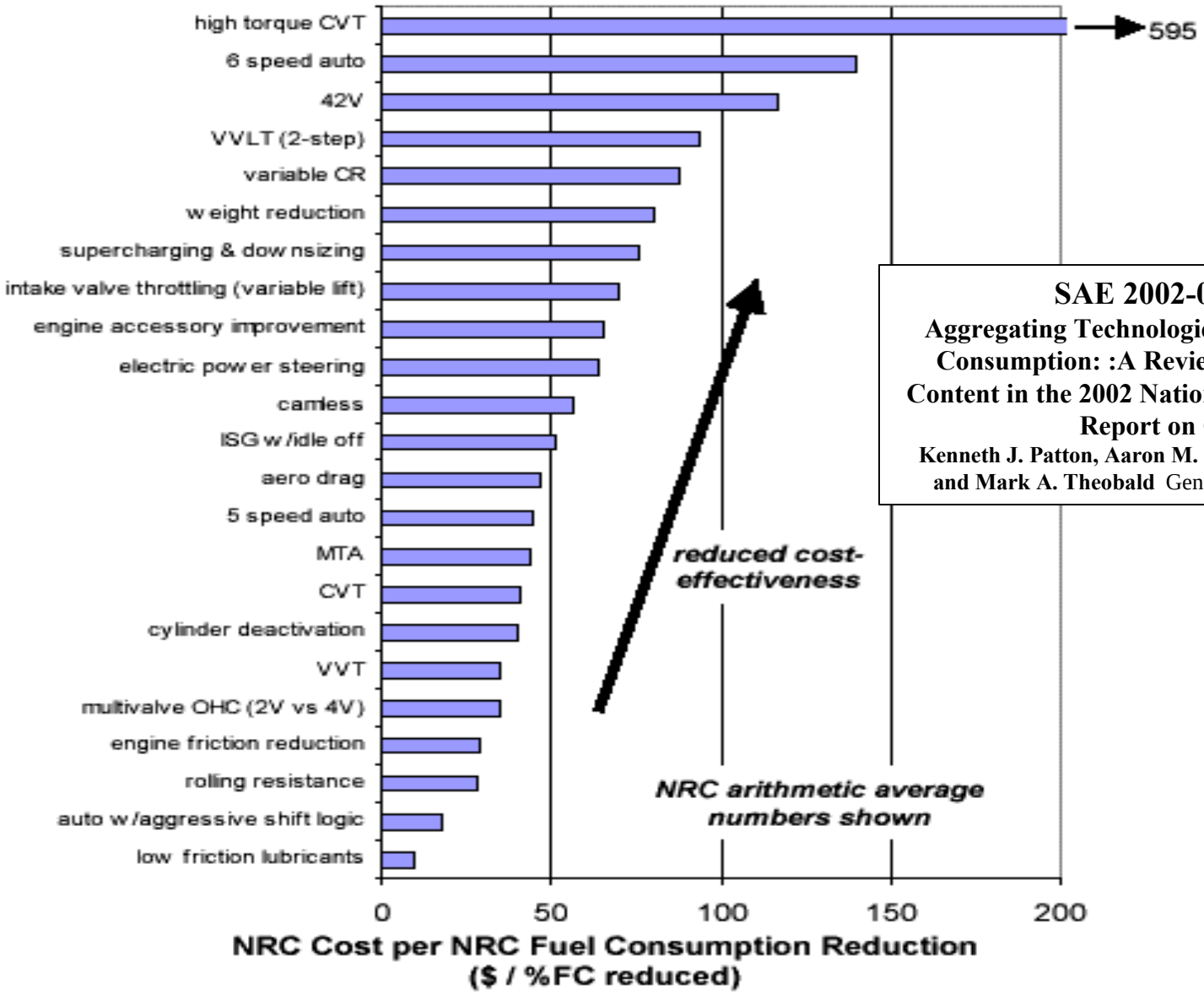


From SAE TECHNICAL PAPER 2001-01-1021

Figure 1 – Schematic showing layout of sub-section of thermoelectric radiator.

Automotive Thermoelectric Applications

- Cost & value - power generation
  - Cost of current systems is low
    - Alternator systems average cost: $60
      - May not be able to eliminate alternator
      - Potential beltless system
  - Added value for power generation
    - Fuel economy improvement
      - Fuel savings ~ $55 to $127 per year
      - Current cost is $20 to $200 for each 1% fuel economy increase
    - Emissions: positive but limited impact



SAE 2002-01-0628

Aggregating Technologies for Reduced Fuel Consumption: :A Review of the Technical Content in the 2002 National Research Council Report on CAFE

Kenneth J. Patton, Aaron M. Sullivan, RodneyB.Rask and Mark A. Theobald General Motors Corporation

Figure 4: Chart illustrating cost per fuel consumption reductions for individual technologies used in the NRC Report (values based on NRC arithmetic average costs and fuel consumption reductions)

Cost and Value of Fuel Economy

	Minimum	Maximum
Cost of conventional alternators (1.5 to 2.0 kW)	$50	$80
Extimated cost of 1% fuel economy improvement with other technologies	$20	$200
Annual fuel cost* - Car avg 27.5 mpg	$682	$682
Annual fuel cost* - Truck avg 20.7 mpg	$906	$906
Fuel economy improvement due to recovered exhaust energy **	8%	14%
Estimated value of recovered exhaust energy:		
Based on annual fuel savings- Car (3 yr.)	$55 ($165)	$95 ($285)
Based on annual fuel savings- Truck (3yr.)	$72 ($216)	$127 ($381)
Cost comparable to other technologies	$160	$2,800

** Based on J. Fairbanks "Stretch" target of 25% TE conversion efficiency

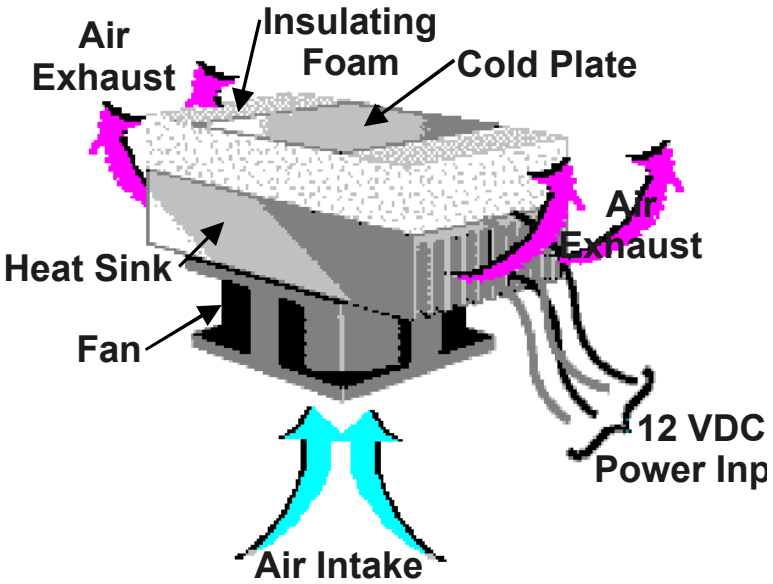
* Based on 15,000 miles driven per year, $1.25 per gallon gasoline

Thermoelectric Cooling / Heating Applications

- AC Systems: Front (4- 7 kW) and rear (1- 2 kW)
- Heater systems: Front (5- 8 kW) & rear (1 - 2 kW)
- Enhance occupant thermal comfort by direct contact
  - Seat & back rest cooling/heating (40-60 W),
  - Headrest cooler (15 W)
- Cooler for steering wheel, gear shifter, seat belt buckle, inside door handles (10-20 W)
- Cold/hot cup holder (15 W)
- Small refrigerated space (Console cooler) (100 W)
  - Safely store tapes, CDs, phone, glasses (15-30 W)
- Electronics cooler (1-10 W)
- Dash cooler(30 W)
- Cool battery tray (30-50 W)

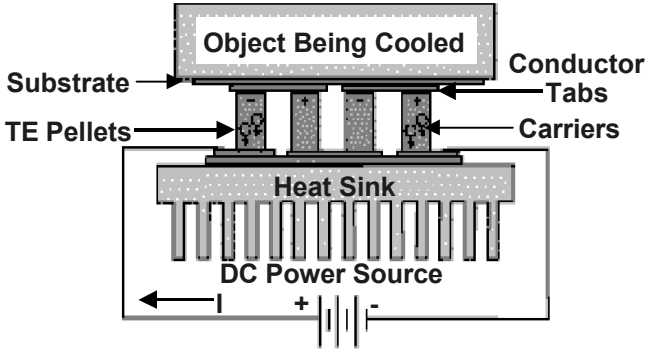
Thermoelectric Cooling - Peltier Effect

Construction:

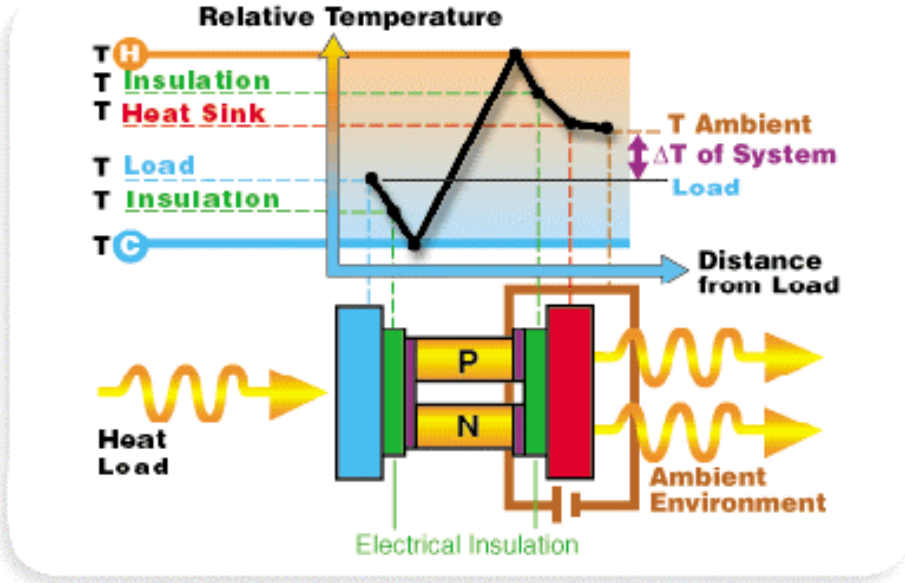


Advantages
- High reliability
- Small size or capacity
- Low cost, low weight
- No moving parts
- Environmentally safe
- Operates as a heat pump, suits EV, HEV, Fuel Cells, etc.

Disadvantage
- Low COP 5-8 % of Carnot



Cross Section



Conventional HVAC System Content & Cost

- Front AC system
  - Conventional vapor compression: condenser, evaporator, module, control, air ducting, refrigerant piping, refrigerant and lubricant.
  - **Cost ~$ 320**, mass~30 kg, A/C Capacity~ 7 kW
- Front Heater - not replaced
- Rear AC System (option on vans & SUV's)
  - Module, evaporator, ducting, refrigerant
  - **Cost ~$100** , mass~7 kg, Capacity~ 2 kW
- Rear heating system
  - Heater core, plumbing
  - **Cost~$40**, mass~2kg, capacity~2 kW

Added Customer Value for TE (= $?)

- Needed features such as pre-cool, rapid heat, supplemental heat
- Enabler for distributed systems
- Lower system noise
- Increased reliability
- Lower lifetime cost & maintenance
- Potentially lower mass
- Environmentally friendly
- ‘Heat pump’ feature for hybrid vehicles

Automotive Thermoelectric Applications

Concerns & Issues

- System use
  - Only 250 W electrical power used on federal test procedure
  - All-electric accessories will allow use of more electric power on FTP and in real-world
  - Hybrid vehicles can use electric power for propulsion
  - Battery storage of power is expensive and inefficient
- System size & location
  - Space is always at a premium
  - Added mass is an issue, especially for fuel economy
  - Incorporating the energy recovery function into the radiator may be easier to package but more difficult to design

Automotive Thermoelectric Applications

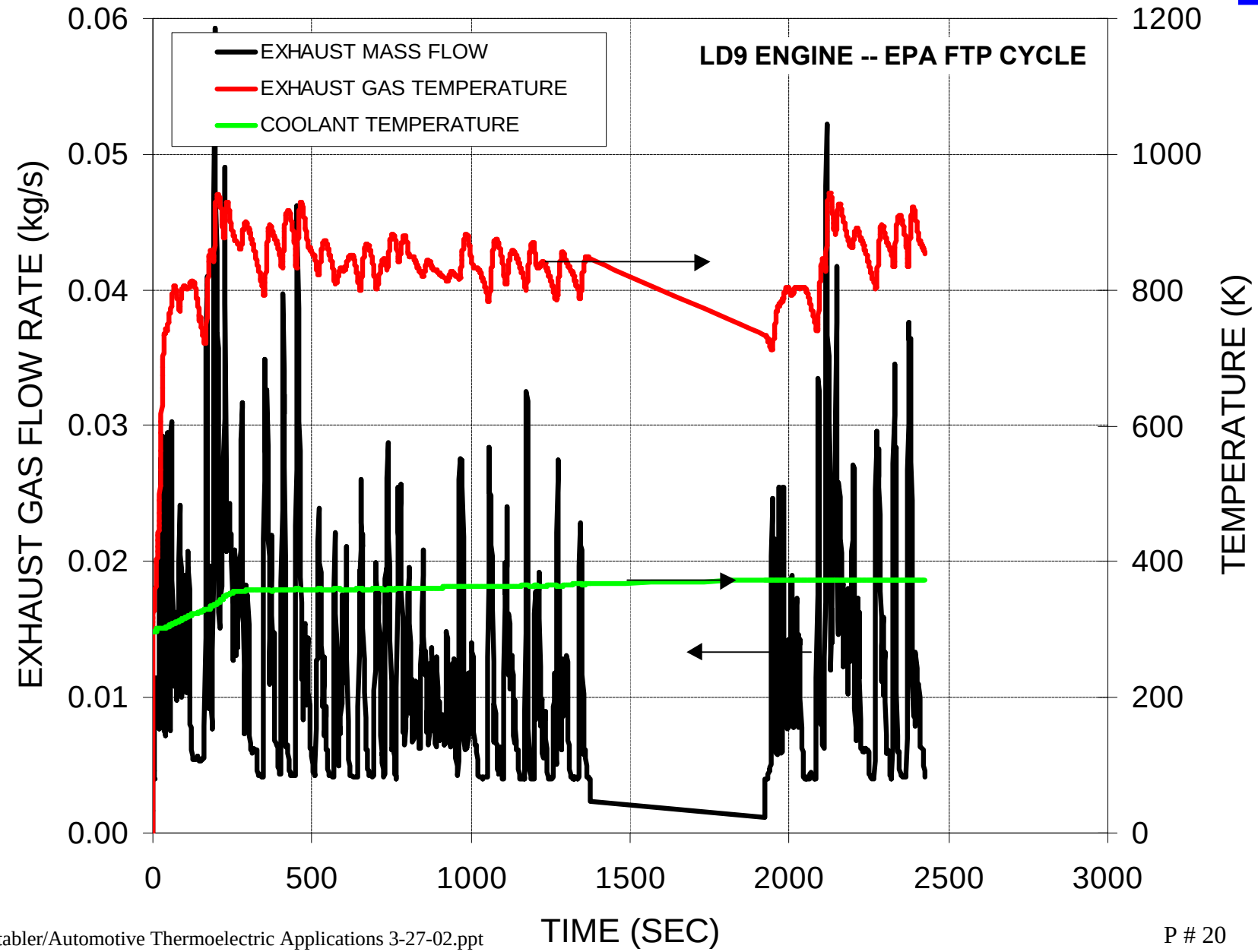
Concerns & Issues

- Thermal management
  - Exhaust gas to conversion devices
  - Conversion devices to air/coolant
  - Potential added radiator heat load
  - For cooling & heating applications
    - Access to and disposal of heat
- Start-up time for power generation
  - Uncertain ability to replace alternator
  - Supplemental fuel burner for fast start
- Cost
  - Very competitive conventional systems

Automotive Thermoelectric Applications
Concerns & issues

- Interface with the vehicle electrical system: 12 or 42 volt systems
- Shift to hybrid powertrains and engine-off-at-idle function
  - Intermittent operation
- Shift to diesel and lean-burn gasoline engines
  - Lower exhaust temperatures & energy
- Replacement of Internal combustion engines with fuel cells
  - 70° C exhaust limits power generation
  - Electric cooling & heating are a good fit with fuel cells

Exhaust flow and Temperatures for a 4 cylinder engine



Preliminary Power Generation Specification

Request for proposal for an electric power generator utilizing engine waste heat (Drafted Aug. 1999)

System or Device:

A system or device to supplement or replace an automotive electrical power generator system with electrical power generated from engine waste heat and providing no load to the engine.

Usage:

Use as primary or secondary electric power generation for passenger vehicles. The primary purpose is to increase the fuel efficiency of passenger vehicles, including trucks.

Request for proposal for an electric generator utilizing engine waste heat

Energy source:

The energy source could be the engine exhaust gas heat over a normal vehicle operating cycle. Typical operating exhaust gas temperatures at the exit of the catalytic converter are 400 to 600 degrees C., with excursions above (up to 1000 degrees C) and below this range. The flow rate will be in the range of 0 to 80 Cubic Feet per Min. The average flow rate for a mid-size car is about 40 CF per Min. The exhaust gases exiting the engine contain up to 40% of the energy from the fuel burned by the engine. Alternatives using of other waste heat sources, such as coolant heat may be considered. The coolant temperature range is ambient temperature up to 125 degrees C and the coolant contains up to 30 % of the fuel energy.

Location:

The preferred location is downstream of the catalytic converter, in the exhaust system. This location is selected to avoid interference with heat up and operation of the catalytic converter. Converter location may be negotiable, as well as heat extraction from upstream of the catalytic converter, if the proposal includes ways to avoid degradation to the converter operation. Location for heat extraction from the coolant would be between the engine and radiator and will require negotiation.

Request for proposal for an electric generator utilizing engine waste heat

Electrical output:

The goal is to generate the maximum power possible, given cost constraints. The voltage delivered to the vehicle should be a nominal 13.5 to 14.5 volt. Proposal should consider the implications of a new 42 volt standard and could focus on this as the operating voltage. Voltage, transients, and EMC must be compatible with a normal passenger vehicle electrical system. Parasitic losses (ignition off, non-generating) should be less than 12 milliwatts. Power provided is defined as the net output; that is, power generated minus any electrical or mechanical power needed to operate the generating system.

Cooling:

The device may use air or engine coolant for cooling. A separate cooling liquid can be considered but must comprehend all cost and service implications. If significant heat is added to the coolant, discussion is suggested regarding the packaging, cost, and other impacts on the vehicle cooling system. Impact of any added fans, pumps, pipes, or cooling surfaces should be addressed.

Ambient air temperature: System design must address starting and operation with -40 to 125 degrees F ambient air temperatures.

Engine coolant temperature: Engine coolant can range from ambient air temperature up to 125 degrees C.

Request for proposal for an electric generator utilizing engine waste heat

Durability:

Expected durability is 5000 hours operation (minimum) over a 10 year/150,000 mile vehicle life. Heat collection devices must survive exposure to exhaust gases, coolant, etc. without excessive degradation (maintenance or service is undesirable, but negotiable) over the useful life of the generator.

Cost:

The cost should be low enough to allow the customer fuel savings to more than pay for the unit. The value of added functionality can be considered. Any deleted equipment will be an offset to the cost (muffler, alternator, etc.). The total cost of the system will be considered, including wiring, power electronics, pipes, pumps, cooling devices, etc. A rough target cost for the system is $100 per kW in production volume (250,000 or greater volume).

Fuel economy savings will comprehend any mass change of the vehicle system by the added equipment. The exact fuel economy savings will depend on the specific engine and vehicle application. Each watt of electrical power generated from waste heat will currently count as a 2 watt reduction in engine load because of typical electrical generator inefficiency. Any value assigned to potential EPA credits for fuel economy is to be determined.

Request for proposal for an electric generator utilizing engine waste heat

Application:

Application of this system is potentially for the full range of GM engines (1.0 to 8.0 liter engines). The proposal may be for all or only a selected portion of this range of engine families. Production volume will depend on cost, size, and value to the customer. Conversion efficiency of the device from heat to electricity will be one of the decision factors.

Size:

The generating unit and all controls, cooling, and other added hardware must be packageable in vehicles using each type of engine. Some packaging requirements are negotiable.

Safety:

The system must not introduce any unusual safety hazards in its operating modes, in failure modes, or in vehicle crashes.