Automotive Applications for Thermoelectric Technology

GM Powertrain, Pontiac, MI

General Motors Corporation

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How big is the automotive market for thermoelectric technology?

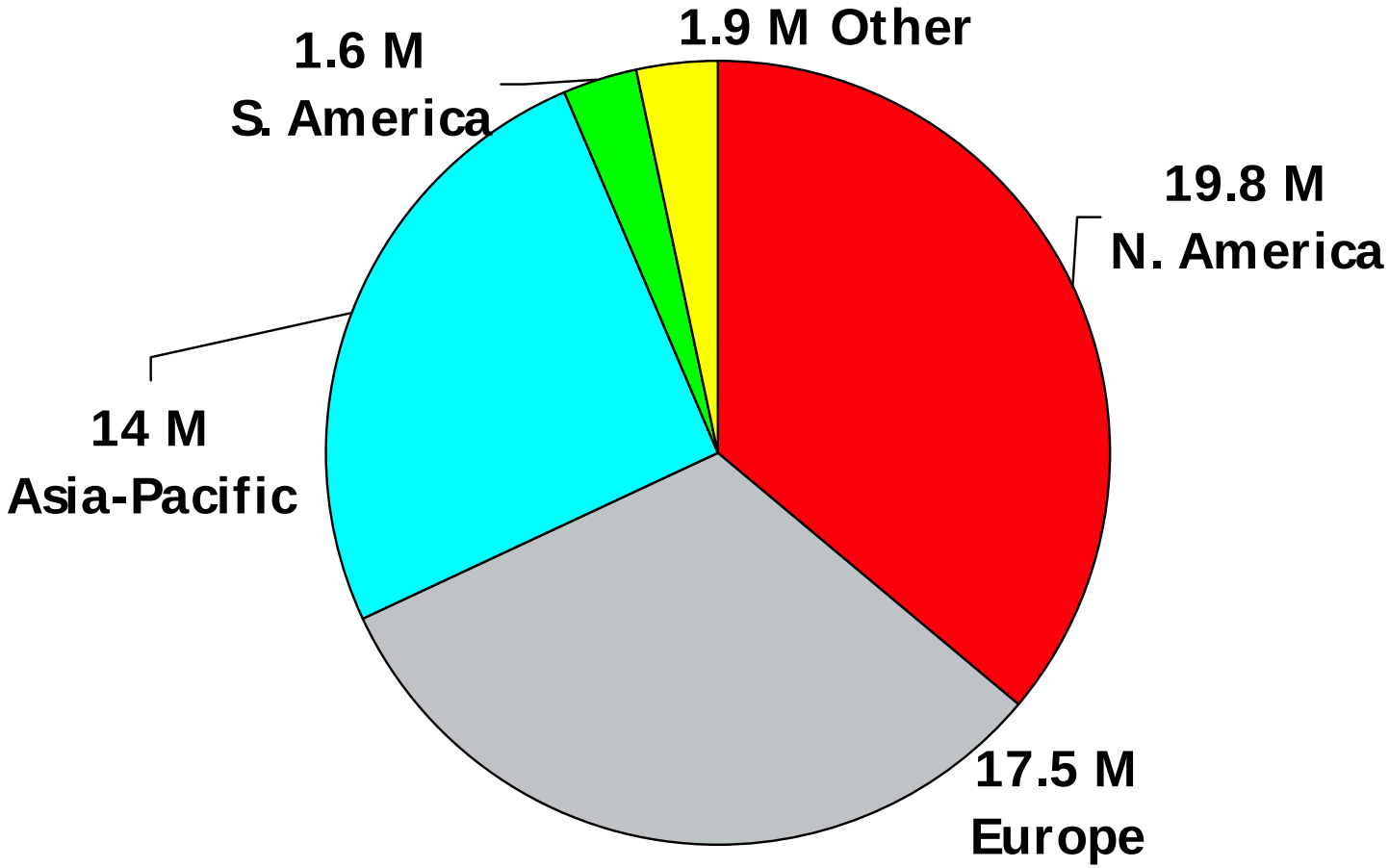
Total size

Applications

Likelihood of applications

Annual World Automotive Sales

54.8 M Cars, Trucks, Buses in 2002



Potential automotive applications of advanced thermoelectrics

Heating & Cooling

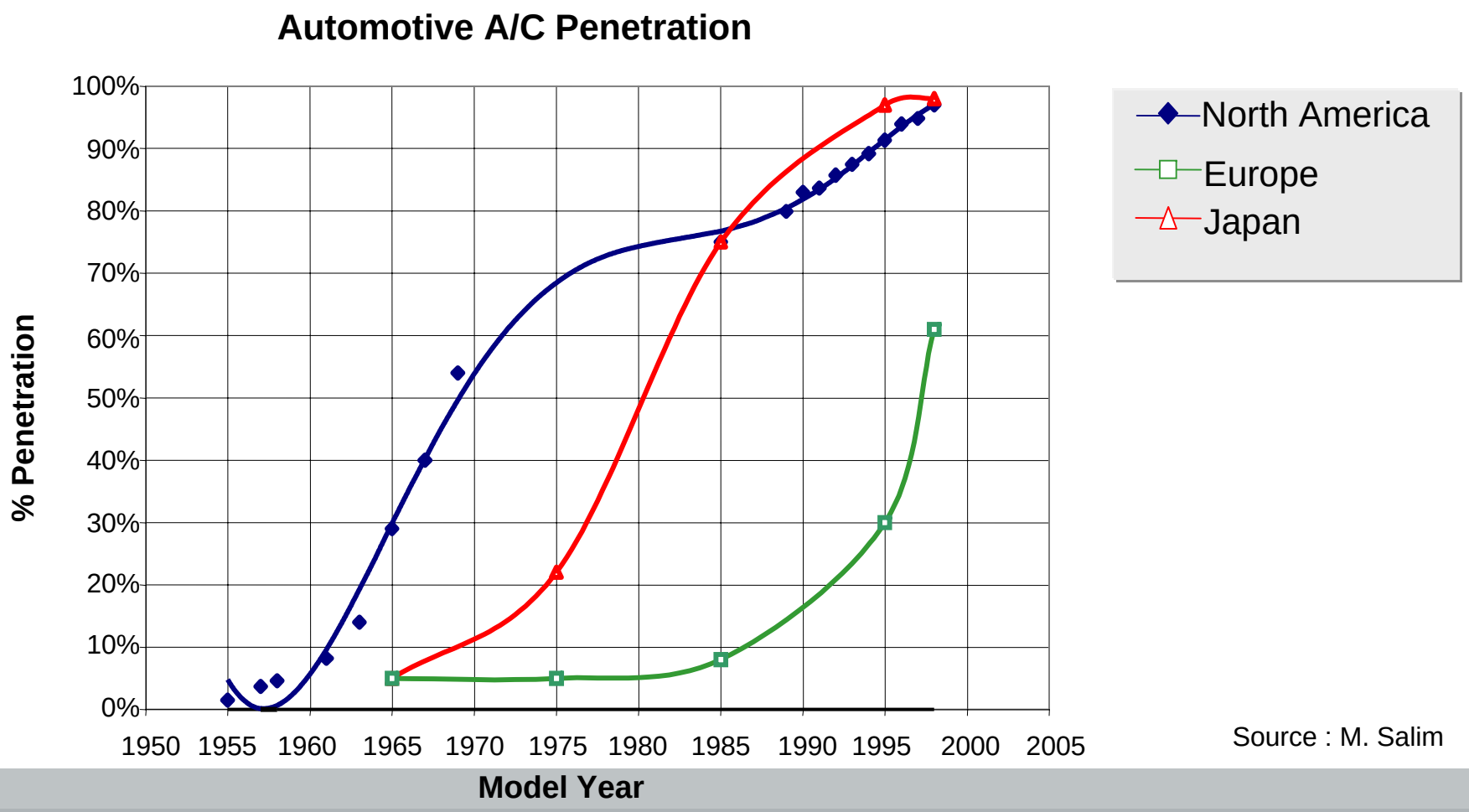
- Passenger Comfort & Convenience
  - Heating, Ventilation & Air Conditioning (HVAC) System
    - Distributed, refrigerant - free systems
  - Seats
  - Cup holders
  - Steering wheel
  - Arm rests
  - Enable hot/cold appliances
- Improve component reliability
  - Battery
  - Electronics

Electric Power Generation

- Waste heat conversion
  - Exhaust
  - Radiator
  - Brakes
  - Other
- Waste heat generators with fuel augmentation
- Fuel burning generators
- Wireless Sensors
- Solar power?

How many vehicles have air conditioning systems?

A/C Penetration Over Time

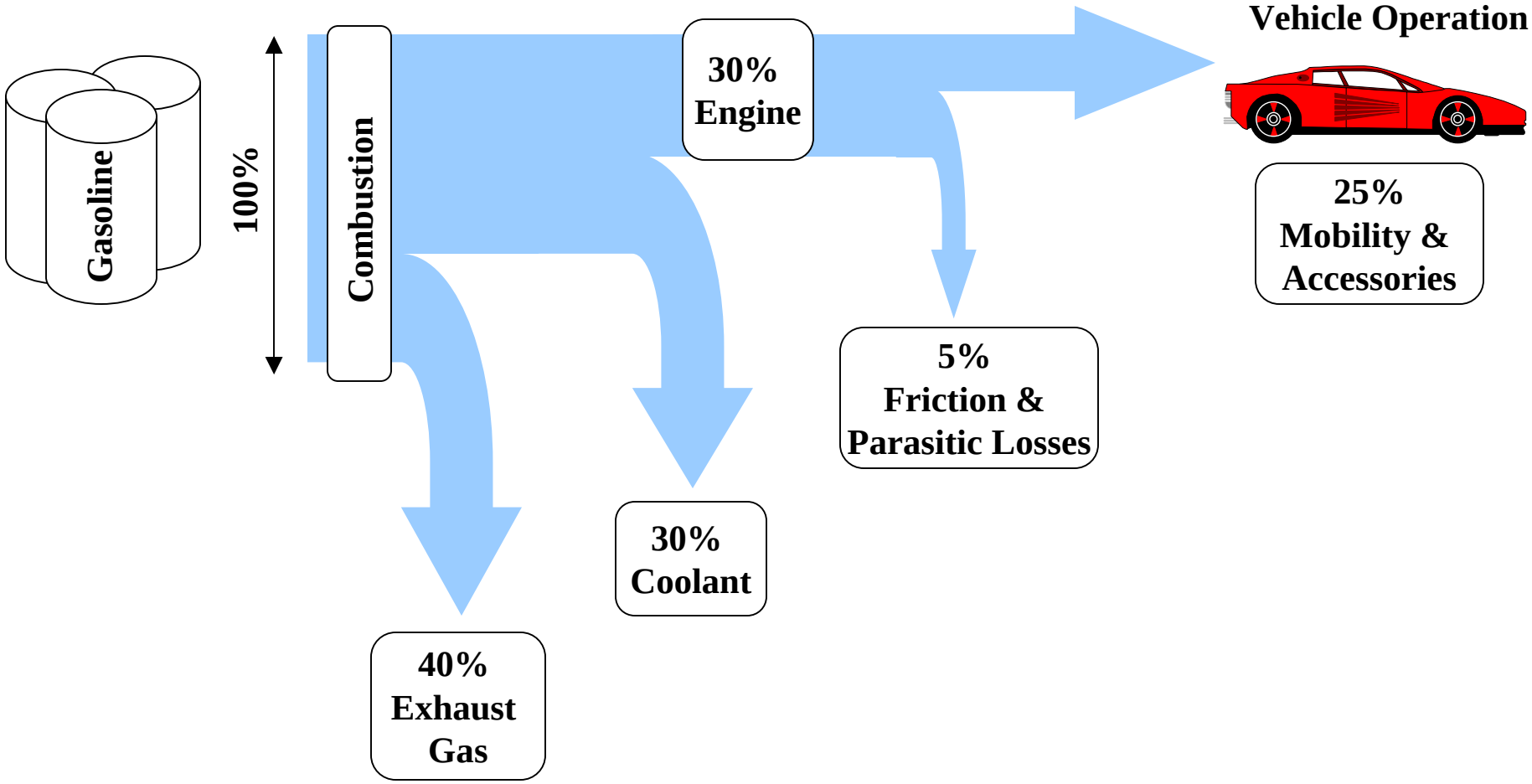


Source : M. Salim

All vehicles have electrical generators; therefore, they are potential customers for advanced thermoelectric generators.

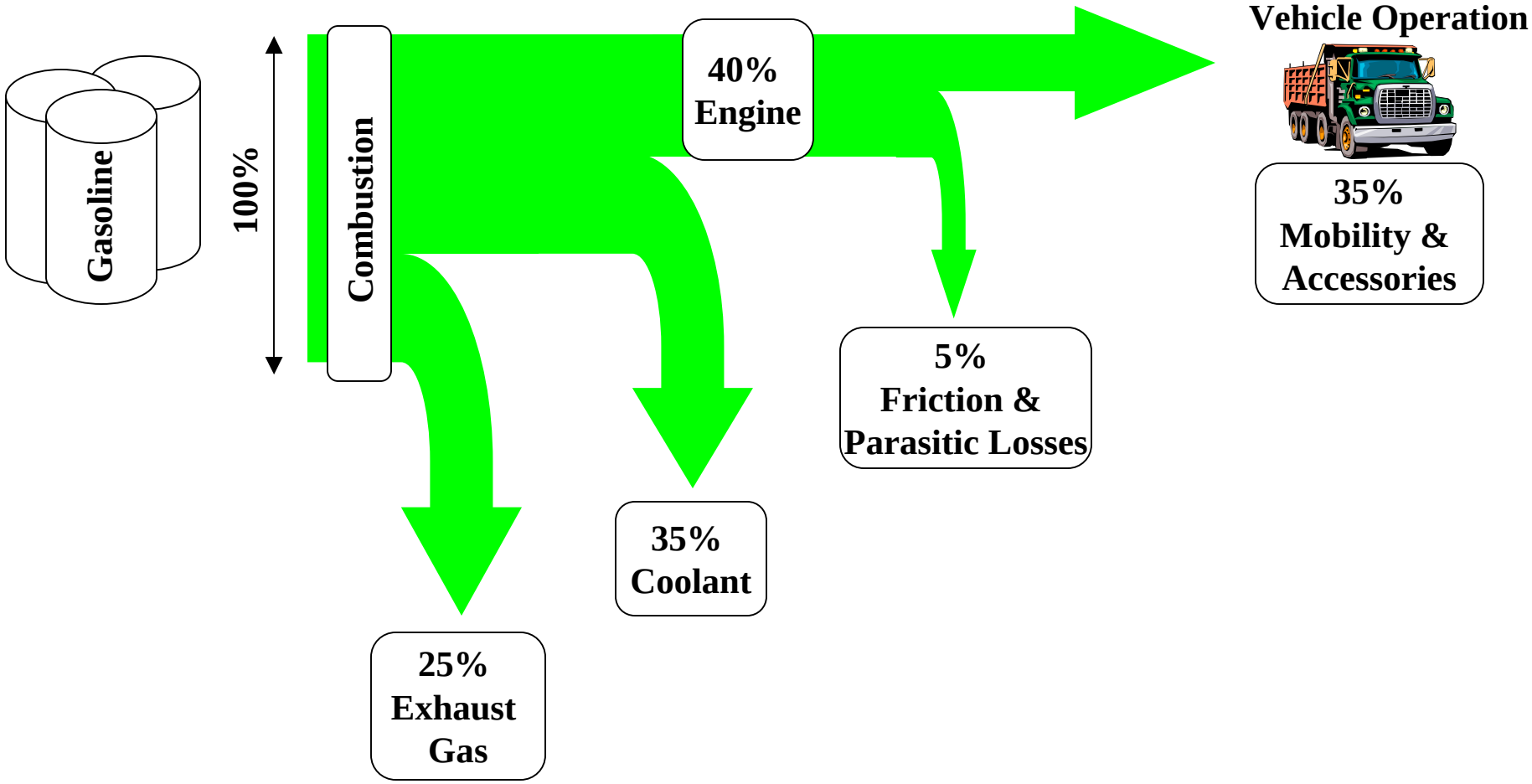
How much energy is available for electric power generation?

Typical Energy Path in Gasoline Fueled Internal Combustion Engine Vehicles



Typical Energy Path in Diesel Fueled, Compression Ignition, Internal Combustion Engine Vehicles

Similar for lean combustion gasoline engines



Considerations for automotive applications of thermoelectrics - long life for the market

Applicable on current and future vehicles

- Conventional gasoline or diesel engine vehicles
- Hybrid vehicles
  - Internal combustion engines as a source of waste heat
  - Opportunity to use “excess” electric power
  - Increased electrical power for accessories
  - Increased need for electric accessories
    - Intermittent mechanical power
- Fuel cell vehicles
  - Large amount of thermal energy at low temperature (80°C)
  - Electric power used for cooling and possibly heating

Considerations for automotive applications of thermoelectrics - good reasons to apply the technology

Heating & Cooling applications

- Resolves greenhouse concerns of refrigerant use
- Enables new design concepts for heating and air conditioning
- Enables new features
- Improves reliability of selected components (Battery, electronics, etc.)

Electric power generation

- Fuel efficiency improvement through waste energy recovery
- High efficiency thermoelectrics may enable fuel powered generators as APU's
  - Supports "engine-off" operation with minimum battery needs
  - Minimize battery losses, cost, & weight
- Increased electric power for new features

How much thermoelectric capability is needed per vehicle? (For cars and light trucks - more for buses & large trucks)

First, consider the possible functions thermoelectrics could perform in vehicles today.

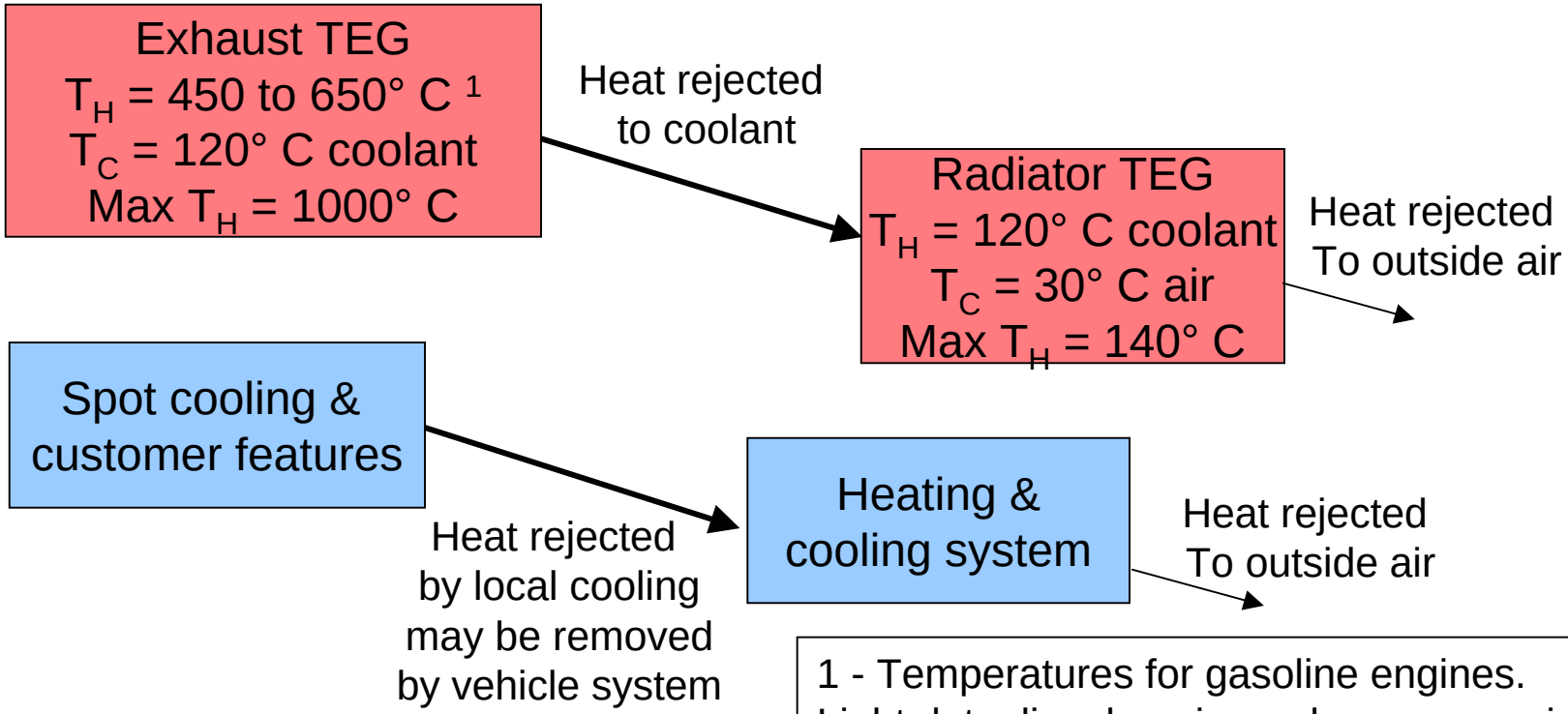
	On Federal Test Procedure (for Fuel Economy)	Typical Real	World Use
		Minimum	Maximum
Electrical Power Needed	250 W	1000 W	2000W
Heating & Cooling Capacity Needed	0 W	3000 W	7000 W

How much thermoelectric capability is needed per vehicle (cars & light duty trucks)?

- **Electric power generation**
  - Minimum: none (thermoelectrics not accepted)
  - Maximum: more is better, challenge vehicle manufacturers to find ways to use all of this “free” power.
    - Could drive vehicle redesign.
    - Low cost & high efficiency could enable very high volumes
  - Likely range: 250w to 2000w
- **Cooling & Heating**
  - Minimum: None
  - Maximum: 7000w refrigeration plus special features like a built in cooler or battery heater/cooler

How many thermoelectric modules per vehicle?

- The number of TE modules per vehicle will depend on module efficiency, cost, system design, thermal energy available, cooling needed, etc.
- Potentially different thermoelectric technology for each use



1 - Temperatures for gasoline engines. Light duty diesel engine or lean gas engine exhaust will be lower temperature (~300° C)

How many thermoelectric modules per vehicle?

- This can be realistically defined only when the subsystems using advanced thermoelectric technology is defined:
  - Functionality relative to the functions they replace
  - Total subsystem cost in medium to high volume (100k to 1M+)

- It will be an iterative process to define the number of modules

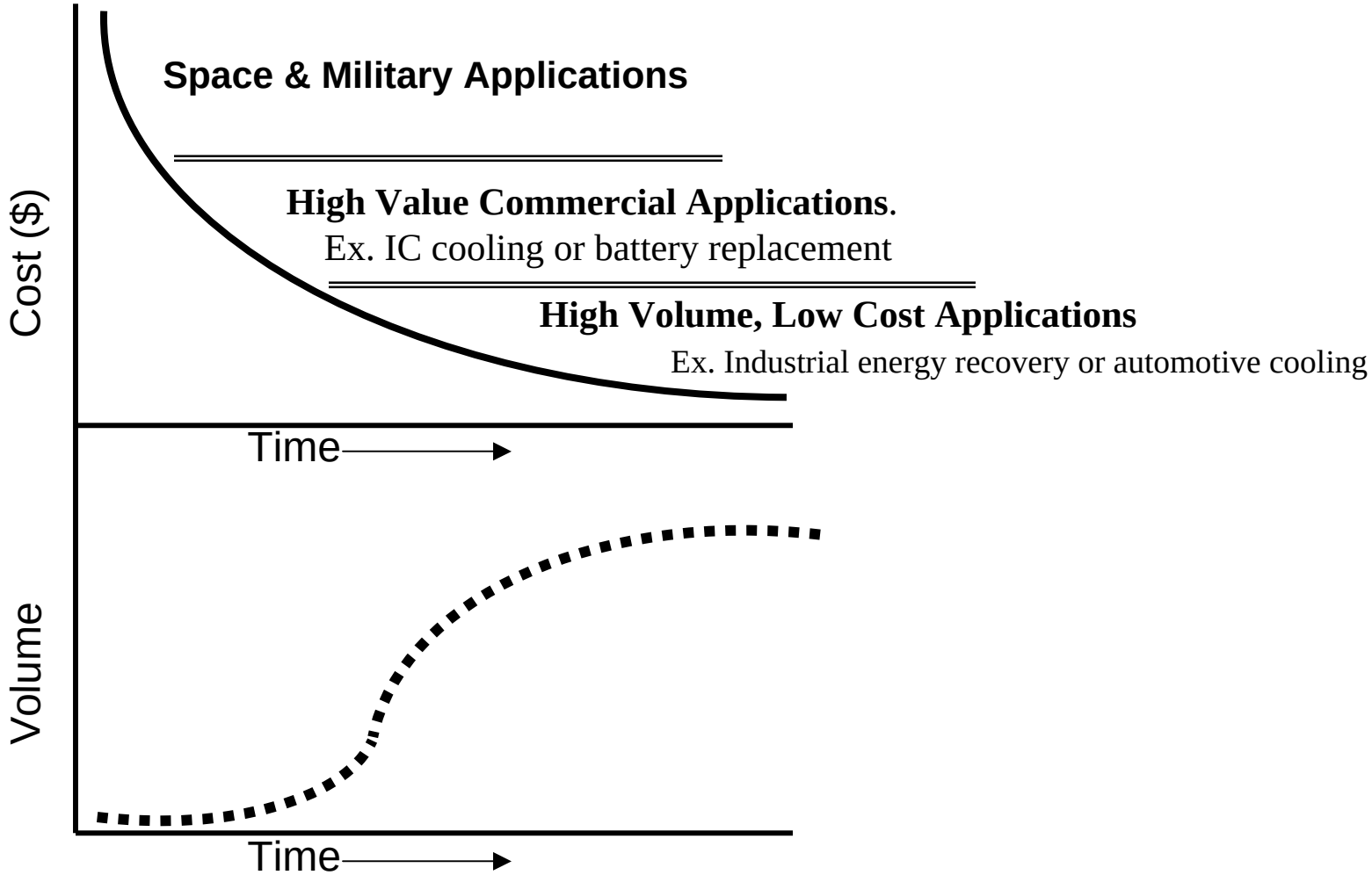
Application Considerations

- The automotive market is very cost sensitive
- Thermoelectric applications will depend on performing functions better or at a lower cost than any alternative
  - Performance will be judged at a system or vehicle level, not thermoelectric module level
  - New or unique features could drive added module demand
- Unique opportunities for heating and cooling exist on hybrid and fuel cell vehicles
  - Increased electric power availability for heating or cooling
  - Intermittent or no direct mechanical power available for AC compressor operation
  - Intermittent heat availability
  - More potential for 'clean sheet' vehicle design
    - New heating and cooling design approaches.

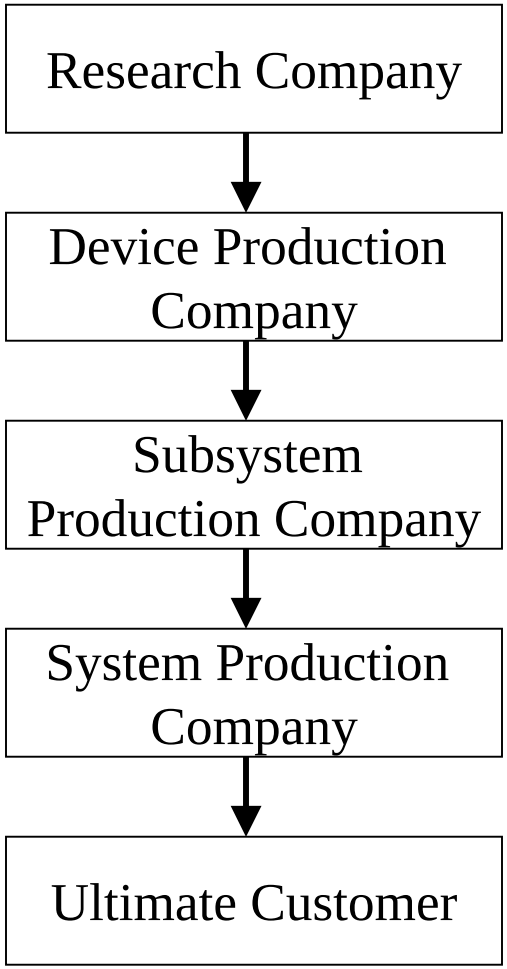
Value of Thermoelectric Technology in Automotive Applications

- **Possible replacement of mechanically driven generator**
- **Value of improved fuel efficiency in generating electric power (v.s. alternative ways to improve fuel economy)**
  - **Value as an enabler of engine-off deceleration and stops**
    - Requires fuel powered capability
- **Value for additional electric power**
  - Enables added features
  - May enable conversion of additional mechanical systems to electrical operation
- **Value for improved HVAC features or lower system cost**
- **Value for new heating or cooling customer features**
- **Value for improved system reliability or durability**

Application, Cost, & Volume Considerations for Thermoelectric Devices



Thermoelectric Commercialization Model



- Each function has to be provided

- One company may provide more than one function

- There could be additional layers

Thermoelectric Commercialization Model

– Automotive Industry

Examples of what:		Examples of who:
- Quantum well, bulk material, …	Research Company	- Hi-Z, RTI, JPL, MSU, Dupont,…
- TE module, electronic controls…	Device Design & Production Company	- Motorola, Intel, TI, Micron, …
- TE generator, HVAC system, …	Subsystem Design & Production Company	- Delphi, Visteon, Amerigon, …
- Car, truck, …	System Design & Production Company	- Daimler-Chrysler, Ford, GM,…
- Customer satisfaction	Ultimate Customer	- You, your neighbor, etc...

Barriers to thermoelectric technology application in the automotive industry

- No clear acceptance of a specific advanced thermoelectric technology
  - Several technologies offer promise
  - Multiple technologies may be needed to provide different functions
- Lack of volume module production for advanced thermoelectrics
- Lack of subsystem designs using advanced thermoelectric technology
  - No clear cost or efficiency information for thermoelectric modules
  - Lack of subsystem production capability
- Uncertain technology functionality, availability and business case prevents vehicle manufacturers from designing subsystems into vehicles.

How real are automotive applications of thermoelectric technology?

•We are here because we think that thermoelectric technology will be applied to a wide range of automotive functions.

•When will this market materialize?

- Today you can purchase a car or truck with features based on current “off-the-shelf” thermoelectric technology.
  - This includes heating and cooling for seats and cup holders
- The automotive industry has not waited for ‘advanced’ thermoelectric materials to be available
  - Innovative subsystem design by suppliers have driven applications
- While market penetration is low today, confined to the luxury segments, it shows promise of growing quickly
- Advances in performance and reduction in cost can quickly increase usage of thermoelectric materials.

The thermoelectric market exists today!

It will take a team effort to grow it with advanced thermoelectrics.

Heated/cooled seats

Picture from Amerigon, Inc.

Applications : Ford, Lincoln, Cadillac, Lexus, Toyota, Infiniti

GMC – heated/cooled cup holder