A survey of state-of-the-art fuel efficiency technologies and designs for passenger cars

ATKINSON CYCLE ENGINES & STOP-START SYSTEMS

Driving Automotive Innovation Conference

Washington DC, September 13th, 2016
Dr. Dean Tomazic, Executive VP & CTO, FEV North America, Inc.

FEV

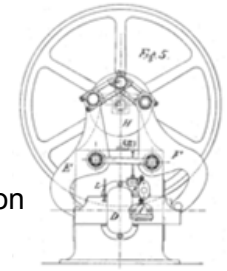
Agenda

- **Introduction**
- **Development Trends**
  - **Atkinson Engine**
  - **Stop/Start Systems**
- **Summary**

ATKINSON ENGINE & STOP-START TECHNOLOGY

Atkinson Engine Technology

- Current conventional engines exhibit efficiency losses due to incomplete in-cylinder expansion
- Atkinson cycle increases efficiency at expense of power density
- Changes to the engines' valve timing and compression ratio mitigate these losses
- Max. engine efficiency demonstrated in field: up to 40% (Toyota Prius)



James Atkinson
Patent (1882)

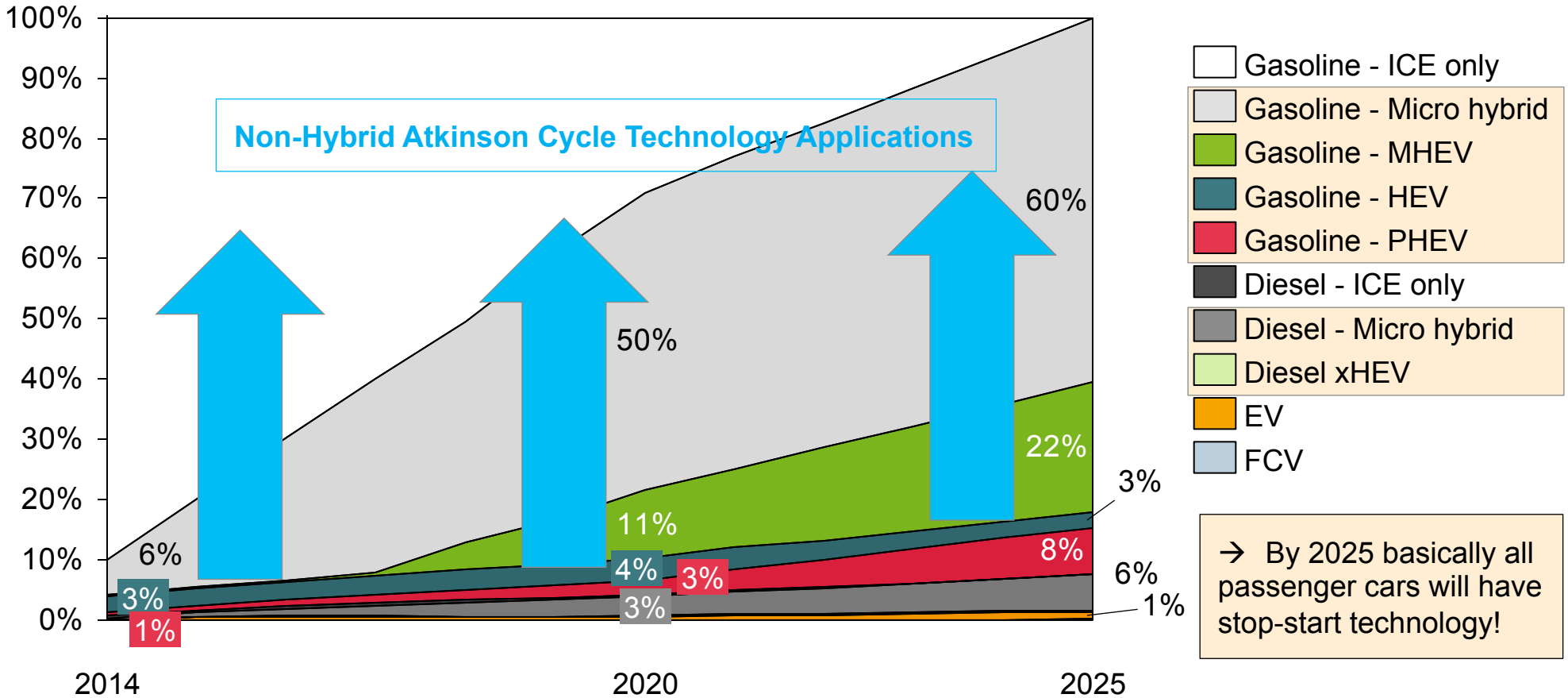
Stop-Start Technology

- Current conventional engines continue running while vehicle is not moving → waste of fuel
- Mechanism to shut off engine when not used and turn it back on quickly is highly desired
- Stop-start systems allow to only operate the engine when needed to propel the vehicle
- System is directly attached to the engine and hence relatively simple
- Impressive improvements in overall fuel consumption demonstrated in the field

Source: FEV research

Development Trends
Engines

FORECAST OF US MARKET SHARES OF POWERTRAIN TYPES*



→ By 2025 basically all passenger cars will have stop-start technology!

* based on analysis of 7 automakers accounting for 75% of US light duty vehicle market
Source: FEV

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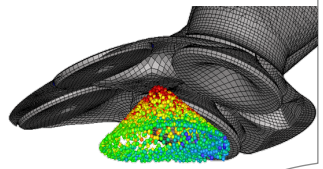
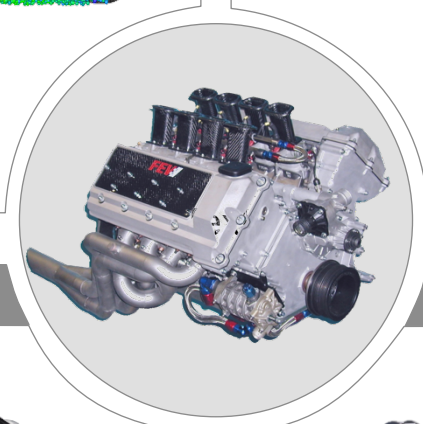
Development Trends
Gasoline Engines

Current and Future Engine Types

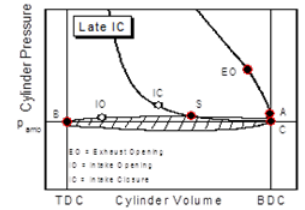
- High-Performance Concept
- Turbo-/Supercharged, DI Concept
- Conventional Naturally Aspirated Engine
- Atkinson (Naturally Aspirated) Engine





Atkinson Engine Features

- Reduced Cylinder Filling
- High Compression & Expansion Ratio
- High Efficiency
- Lower Peak Power
- Low Cost



Atkinson Engine Applications

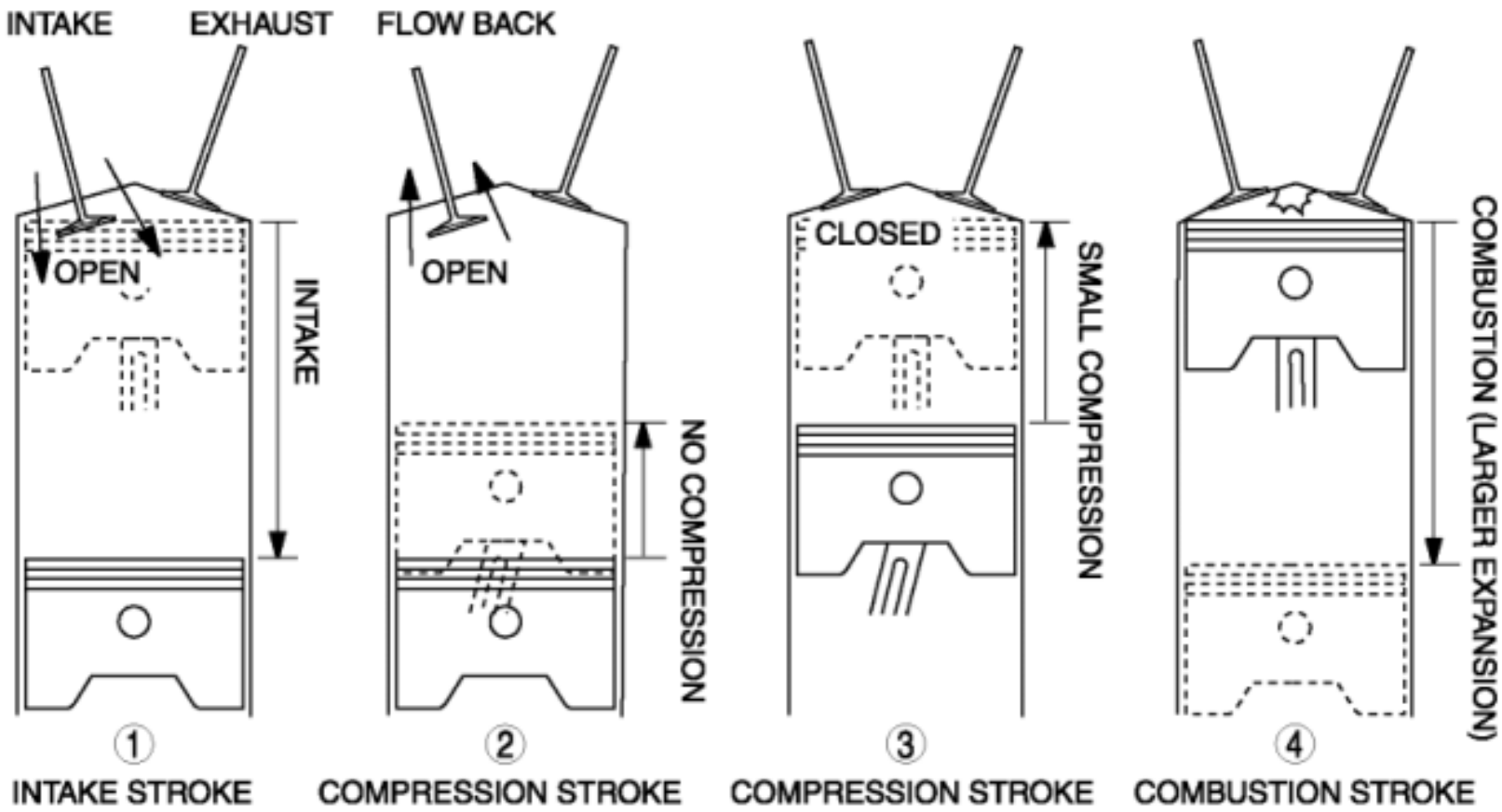
- Full Hybrids
- PHEV's
- Prime Mover
- Low Cost/Power Applications

Atkinson Engine Opportunities

- Friction Reduction & Stop/Start
- Advanced Thermal Management
- Cylinder Deactivation
- Variable Camshaft Profiles
- Variable Compression Ratio (VCR)

Source: FEV research

ATKINSON ENGINE TECHNOLOGY PRINCIPLE: EXTENDED EXPANSION

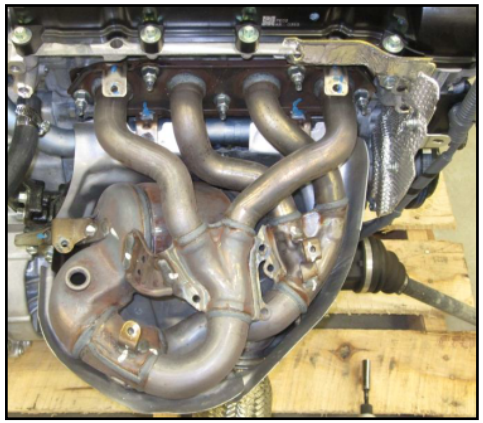


Source: FEV research

Development Trends
Gasoline Engines

ATKINSON ENGINE EXAMPLE 1: MAZDA 2.0L SKYACTIVE-G

- 2.0L I4 DI Atkinson cycle engine
- Power: 155 hp (115 kW) @ 6,000 rpm
- Torque: 150 lb-ft (203 Nm) @ 4,000 rpm
- High compression ratio of 13:1

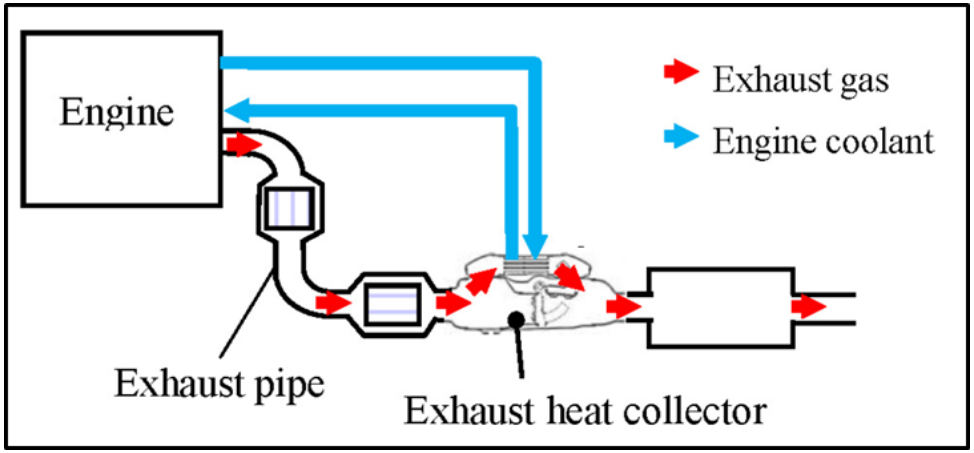


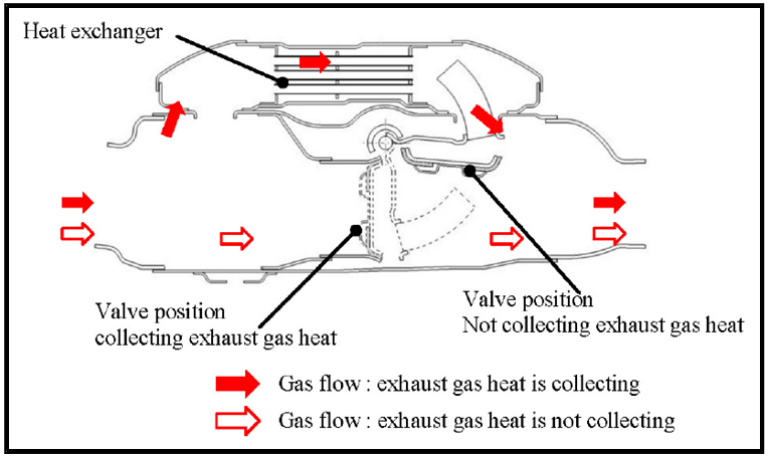
Source: FEV research

Development Trends
Gasoline Engines

ATKINSON ENGINE EXAMPLE 2: TOYOTA PRIUS 1.8L I4

- 1.8L I4 PFI Atkinson cycle engine
- Power: 95 hp (71 kW) @ 5,200 rpm
- Torque: 105 lb-ft (142 Nm) @ 3,600 rpm
- Max. brake thermal efficiency: 40%
- High compression ratio of 13:1
- Exhaust waste heat recovery (WHR) system





Source: FEV research

Development Trends
Stop/Start Technology

STOP/START TECHNOLOGIES

Technologies and Benefits

Types of Stop/Start Technologies:

- Belt-Starter Generator (BSG)
  - P0/P1f application (12 or 48V)
  - Belt driven via crankshaft
  - CO_2 reduction potential: ~ 4-6% (12V-FTP)
  - CO_2 reduction potential: ~ 10-12% (48V-FTP)
- Integrated Starter Generator (ISG)
  - P1 (direct drive) application (48V)
  - Integrated between engine and transmission
  - CO_2 reduction potential up to 18% (48V-FTP)
- Enhanced Electric Starter
  - Enhanced due to higher number of starts
  - CO_2 reduction potential: ~ 3-5% (12V-FTP)

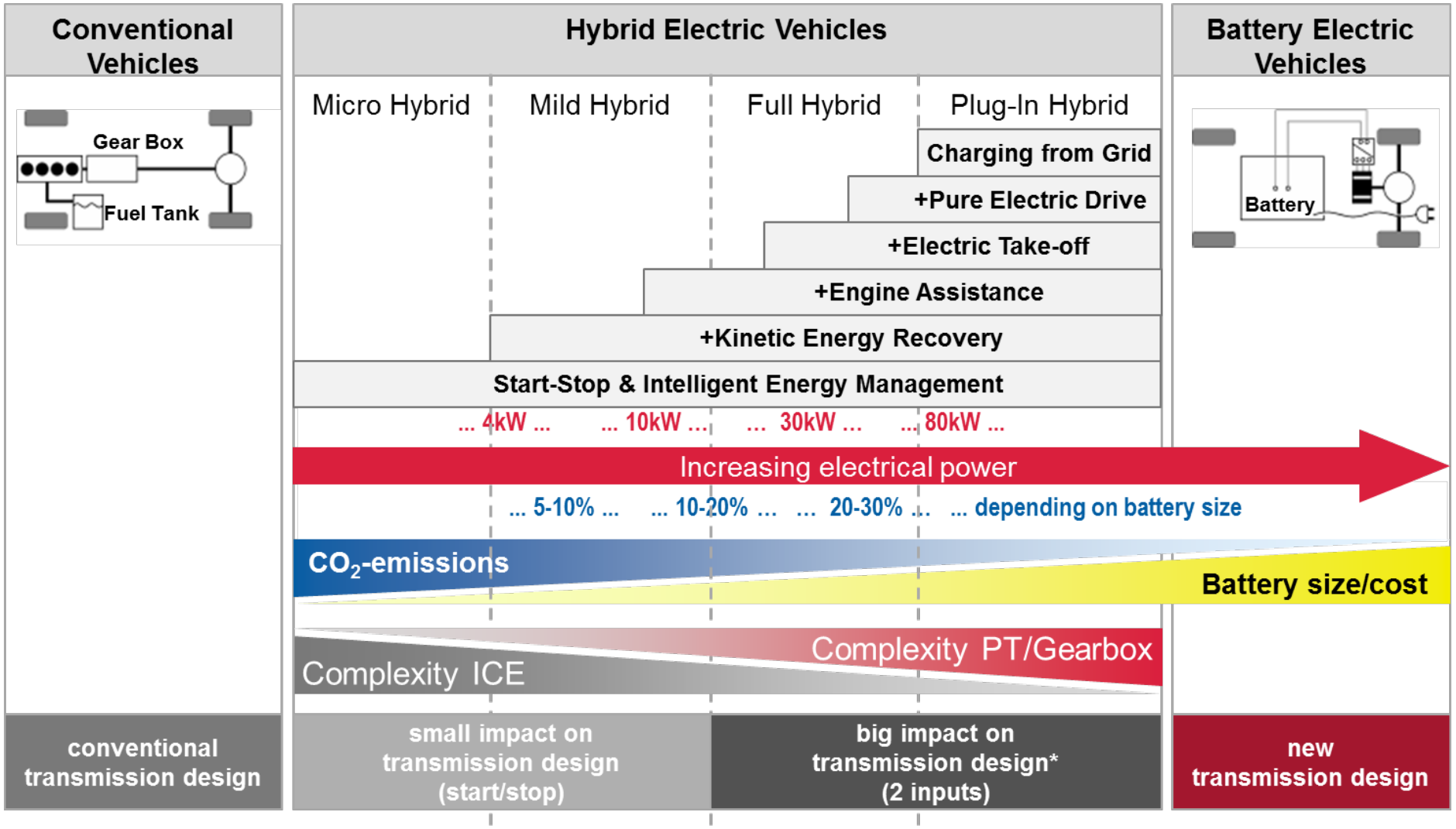
Customer Acceptance

Important Consumer Acceptance Criteria:

- Noise-Vibration-Harshness (NVH) behavior of system during engine start and vehicle launch (comfort, change of mind situation) → Fast and smooth
- NVH behavior of system during engine stop
- Launch delay and vehicle hesitation
- Possibility for deactivation (via driver)
- Fuel consumption reduction
- A/C switch off during stop phase
- Vehicle price increase due to increase system cost
- Concern of increased engine wear due to significant increase of amount of restarts

Source: FEV research

Development Trends
Hybridization / Electrification / Transmissions



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Summary

- **The industry is facing multidimensional challenges from a legislative, economic and societal perspective. Technical solutions must satisfy all of these requirements to succeed in the marketplace.**
- **Market shares of different technologies have been estimated and corresponding technologies developed accordingly. However, different markets have different requirements and hence different technical solutions.**
- **The Atkinson cycle engine has a lot of potential for HEV/PHEV applications as well as non-hybrid engine applications and can be combined easily with other promising technologies such as VCR and cylinder deactivation.**
- **The stop/start technology offers great benefits in terms of fuel consumption and emissions reduction. Its penetration rate over time in the U.S. market will also depend on the applied level of sophistication within the corresponding applications due to current customer experience and future expectations.**
- **Due to the large benefit of stop/start, it can be expected that by 2025 each new vehicle will offer that capability.**

