Vision: Connected World

Industry  Mobility  Energy  Smart Home  Smart City

Li Jiang
Advanced and System Engineering
Gasoline Systems
Increasingly stringent legislative targets pushes new technologies.
Evolution of Electrification

CO₂ Reduction Potential

Electrification Level

Start/Stop

Advanced Start/Stop

µHEV

Start/Stop

Coasting

<60V

Coasting

Recuperation

Boost

e-Drive

PHEV

Coasting

Recuperation

Boost

e-Drive

Start/Stop

Coasting

Recuperation

Boost

e-Drive
ARPA-E Powertrain Innovation Workshop

2020 Engine and Transmission Technologies Projection

Production projections confirm the trend toward advanced powertrain concepts and ramp up of electrification.
Powertrain System Domains

**Internal Combustion Engine (ICE)**
Improvements of up to **15%** by downsizing, combustion concept and operation strategy

- Air Management
- Fuel Injection & Ignition
- Fuel Supply
- Turbocharger

**Transmission Control & Components**
Improvements of up to **10%** by allowing for optimal ICE operation, mechanical and actuation efficiency

**Electrification**
Additional benefit of as much as **35%** by recuperation and ICE relief

- Power Electronics
- Electric Drives
- Battery incl. Control

**Baseline Vehicle:**
- 1300kg Compact Car
- 2.0L gasoline PFI natural aspirated
- 6-speed AT

What will be the impacts of Vehicle Connectivity and Autonomous Driving?
Connected Vehicle technologies provide preview into the future, enabling determination of optimized trajectory for powertrain.
Autonomous Driving allows decoupling of driver inputs, allowing optimized dynamic powertrain control for improved efficiency.
Opportunities and Challenges

**Control**

- **Predictive Control**
  How much preview is required for real-time optimization? ...

- **Control Models with more details**
  How much details are required? Data-driven online adaptation? ...

- **Real-Time Vehicle Individual Optimization**
  On-board or off-board computation? What is the communication protocol? OEM calibration certification? ...

**Powertrain: Engine, Transmission, Electrification**

- **Operation Strategy Optimization**
- **Minimize Abrupt Transient Operations in Engine**
- **Enable Engine Technologies with High Efficiency but Compromised Performance**
  How will this complement the evolution of electrification? ...

How to account the real-world benefits towards fuel economy certification?
The synergies among Electrification, Connected Vehicles, and Autonomous Driving maximize fuel efficiency potentials of powertrain strategies

VCR: Variable Compression Ratio | COD: Cylinder On Demand
Example: Multi-Mode Combustion

Preview into the future helps avoid unnecessary combustion mode switches, resulting in 1-2% drive-cycle fuel economy improvement.

Penalty for unnecessary switching of combustion modes:
- Fuel economy
- Time / Performance

Research in collaboration with Powertrain Control Laboratory at University of Michigan (S. Nüesch, A. Stefanopoulou)
Example: Optimized Transmission

**Concept**

1. Future vehicle speed trajectory is known

![FTP 75 Drive Cycle Gear Optimization](image)

2. Transmission gear optimized for better efficiency while still meeting upcoming performance requirements

![Graph of Engine Speed vs. Engine Load](image)

**2. Measurement Data**

Optimal strategy involves upshifting & downspeeding where possible

<table>
<thead>
<tr>
<th>Cycle</th>
<th>FTP-75</th>
<th>HWFET</th>
<th>Combined Cycle</th>
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</thead>
<tbody>
<tr>
<td>Original [mpg]</td>
<td>24.0</td>
<td>38.5</td>
<td>28.9</td>
</tr>
<tr>
<td>Optimized [mpg]</td>
<td>27.5</td>
<td>40.0</td>
<td>32.0</td>
</tr>
<tr>
<td>Improvement [%]</td>
<td>+14.6%</td>
<td>+3.9%</td>
<td>+10.7%</td>
</tr>
</tbody>
</table>

Efficiency gains are significant

Transmission strategy optimization can enable significant fuel economy savings

Research in collaboration with Powertrain Control Laboratory at University of Michigan (S. Nüesch, A. Stefanopoulou)
Example: Start-Stop Coasting

Start/Stop Coasting

- Drivetrain Open/Engine Off
  - Engine
  - Transmission
  - Engine Open, Transmisssion
  - Increased rolling distance

- Reduced Drag Torque
  - 6th gear, Fuel Cut-off
  - Rolling Distance

- Fuel Savings (real-world)
  - Up to 10%
  - ~4%

New system challenges:

- New system solutions:

Impact on Powertrain

- Engine Off Time
  - +27%
  - Start/Stop Coasting
  - ~10%
  - Start/Stop

- Engine Restarts
  - Stress for engine starter system and power-net
  - ~350k...400k
  - +<200k
  - ~150k...250k
  - Start/Stop Coasting
  - Start/Stop

Roadblocks

- Regulatory
  - Certification cycles do not support SSC (fixed speed profile)
  - Off-cycle credits can be awarded, but data collection needed from the real-world fleet tests

- Technical
  - US market dominated by Step-AT transmissions; which do not inherently support SSC (requires design changes)
  - Power-net stabilisation needed for functional safety and robustness (synergies to 48V)
Synergies for Start-Stop Coasting and 48V mHEV

BRS Features (User Experience)

**Engine start:**
- Start quality and response time is attractive for SSC
- Enables high number of start cycles not possible with existing systems

**CO₂ benefit:**
- Benefit of Coasting and Recuperation are typically additive
- Improved regenerative braking at 48V is used to supply power net during coasting phases
- Use cases are independent from each other:
  - “coasting” if driver releases gas pedal, “recuperation” if driver presses brake pedal

**System requirements:**
- mHEV power nets are “SSC ready”:
  - 2nd energy storage (redundancy)
  - Robust with respect to charging/decharging cycles
  - High dynamic charge acceptance (efficient recuperation)
Start-Stop Coasting w/ DCT in Real World

Cycle data:
- 31 mi / 56 min driving
- 12 mi Interstate (39%)
- 15 mi >40mph (48%)
- 4 mi <=40mph (13%)
- most common St/St

DCT: Dual Clutch Transmission
Driver Impacts on Start-Stop Coasting

Change in MPG

City
- 5.21%
- 23.89%

Highway
- 5.46%
- 7.95%
- 5.36%
- 16.31%

Overall

Drive Mode Distribution, Average Distribution:
- Coasting: 71%
- Stop: 21%
- Engine On: 8%

Drive Mode Distribution: Best Performer without Instruction:
- Coasting: 51%
- Stop: 38%
- Engine On: 11%

Drive Mode Distribution: Educated Operator:
- Coasting: 37%
- Stop: 54%
- Engine On: 9%
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Günter Radtke, 1974