“Focus on the Future”
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Powertrain Strategies for the 21st Century:
How Are New Regulations Affecting Company Strategies?

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Though there are varied, and region-specific, needs, “Regulatory” requirements play an increasing role with respect to strategic direction.
Passenger cars and light-duty trucks contribute approximately 20% of U.S. and ~11% of global CO₂ emissions.

Vehicles are a significant source of greenhouse gas emissions but are not the major source.
Aggressive CO₂ / FE regulations in Europe and the U.S. require major product portfolio actions to achieve compliance.
New government requirements in the U.S. reflect a significant increase in both the level and implementation timing of the fuel economy standard.
Ford employs a total vehicle approach to identify cost effective solutions, combining significant weight reduction, advanced technologies, and powertrain rematching.
Technology Migration Strategy

Near Term
- Significant number of vehicles with EcoBoost technology
- Transmission: Dual clutch & 6-speed replace 4- and 5-speeds
- Increased hybrid applications
- Increased unibody applications
- Introduction of smaller cars and CUVs
- Electric power steering
- Battery management systems
- Aero improvement up to 5%
- Research and development in hybrids, bio-fuels, and fuel cells

Mid Term
- Weight reduction of 250 - 750 lbs
- Engine displacement reduction aligned with weight save
- EcoBoost available in nearly all vehicles
- Increased use of hybrids as a percentage of gas engines
- Diesel use as market demands
- Additional Aero improvements up to 5%
- EPAS approaching 100% on light-duty vehicles
- Introduction of plug-in hybrids and BEV

Long Term
- Percentage of internal combustion dependent on renewable fuels
- Volume expansion of Hybrid technologies
- Continued leverage of PHEV, BEV
- Introduction of fuel cell vehicles
- Clean electric / hydrogen fuels

In the Near- and Mid-term, Ford will broaden its portfolio application of EcoBoost and hybridization technologies.
- There is a common technology path for 4V DOHC engines that employs Twin Independent Variable Cam Timing and may incorporate Direct Injection.
- A significant trend will be toward boosting and downsizing as an important fuel economy and CO₂ improvement opportunity.
Baseline: **Naturally aspirated PFI engine**
- Torque / liter is modest
- Good BSFC over a small region of the map
- Fuel consumption is favorable only at high loads

The following slides explain the **Steps to EcoBoost**:
1. Boost the engine
2. Downsize to equal power
3. Downspeed to equal vehicle top speed
EcoBoost Basics 1/3: Boosting and Direct Injection

**BSFC vs. BMEP @ 2,000 rpm**
- Naturally Aspirated
- Ecoboost I

**BMEP vs. RPM**
- Green circle (G) represents 80 kW/L
- Red circle (F) represents 53 kW/L

### Step 1: Boost & convert to Direct Injection
- Torque / liter can be nearly doubled
- Power / liter increased by 1/3 to 1/2
- Good BSFC region of the map significantly expanded
- DI required to minimize compression ratio loss
- Higher power & torque => potential to **downsize**
Step 2: Downsize the engine to equal power

- Now look at absolute torque and power
- About 1/3 less displacement needed for same power
- Typically means using the next smaller engine family
  - => lower friction & cost
- More torque than original engine => better performance
- Region of good BSFC shifted to operating areas of higher usage
- Lower rated speed => potential to downspeed
Step 3: **Downspeed the engine to match the vehicle top speed**

- Now look at tractive force vs. vehicle speed
- Tractive force matches original => also grade, towing
- Freeway fuel consumption much improved - approx. 10%
EcoBoost – Next Generation with increased BMEP capability will enable further downsizing, as well as improve BSFC through the application of cooled EGR.

Next Generation technologies can be synergistic with hybrid applications.
EcoBoost - Next Generation: Performance & Fuel Economy Benefits

- Advanced boosting for wider torque curve
- Cooled EGR for improved fuel consumption
- Knock mitigation:
  - EGR @ full load
  - Ethanol
Long-term EcoBoost solutions may include more advanced, multi-stage boost systems for higher BMEP capability over a wider range, and extended dilute combustion range.

Various types of “lean” operation are also being investigated for improved BSFC.

Increasingly stringent emissions regulations drive significant research and development efforts in both engine combustion and aftertreatment systems design.
EcoBoost – Advanced: Performance & Fuel Economy Benefits

EcoBoost - Advanced

- Multi-stage boosting for wider torque curve and broad application of cooled EGR
- Engine de-throttling technology for part load fuel consumption
EcoBoost & Future Technologies – Challenges

**Near-term:**
- **Cold start crank and run-up emissions** are much more challenging in a DI engine (versus PFI).
- Turbocharging negatively impacts engine cold-start since it requires more **heat to light off catalyst** due to heat lost to the turbo system.
- **Fuel Mixing in:**
  - a DI engine is much more complicated than PFI, over the entire speed and load operation map.
  - boosted operation is further complicated due to the denser intake flow pushing the fuel spray away from its designated trajectory.
- Higher torque density operation is more prone to **knock** than naturally aspirated engines.

**Mid-term:**
- **Low-speed pre-ignition** (LSPI, a.k.a. Mega-knock) is:
  - sporadic pre-ignition followed by knock
  - observed at low-speed / high-load
- **Transient Control of cooled EGR** - in large amounts - affects combustion rate, knock and misfire.
- **Vehicle Launch** will become a greater challenge with increased down-sizing as the initial torque is naturally aspirated.

**Long-term:**
- **Emissions Challenges become increasingly stringent**
  - Evolution of standards driven by stoich capability
  - 100% SULEV becomes the next level
  - Particulates will be added to the requirements
  - Lean aftertreatment capability also improves, but is always substantially less than stoich capability
Summary / Conclusions

- **EcoBoost** engines are now in production. They will provide significant performance and fuel economy benefits to our customers at good value.
  - Many new technical challenges faced during development.
  - Many lessons learned and new CAE and experimental capabilities developed along with the countermeasures which will be applied to future programs.

- **EcoBoost – Next Generation**, currently under Advanced development, will provide greater performance and fuel economy benefits to our customers, but will provide challenges in transient EGR control and vehicle launch with more aggressive downsizing.
  - Next Gen technologies can be synergistic within hybrid applications

- **EcoBoost – Advanced** technologies, including multi-stage boost systems and dilute / lean combustion systems, offer potentially significant incremental fuel economy improvements. Realizing these benefits will require substantial developments in combustion and aftertreatment technology.

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EcoBoost will continue to be a key part of the future engine technology strategy, with significant technology growth potential.
BACKUP
Certain technologies are synergistic when combined with downsizing & boosting, especially in higher-load applications, while others offer limited incremental fuel economy benefit.
Ford continues to expand electrification offerings across the portfolio. Advanced ("Next Gen") EcoBoost engines will play a key role in optimizing hybrid applications.
Engine Technology Path

Diesel

- Bio-Fuels and Flex Fuel
  - Ethanol
    - E10-E100
  - Butanol
  - Ethanol Boosting
  - PZEV Challenges

Gasoline

- Base Engine
  - Reduced Throttling
    - VCT
    - CVVL
  - Dilute Combustion
    - EGR
    - Lean
    - HCCI
  - Friction Reduction
  - Advanced Cooling
  - Fast Warm up

Hybrid P/T

- EcoBoost
  - EcoBoost I
    - GDI
    - Turbo-Charged
  - EcoBoost II
    - Advanced Boost
    - Cooled EGR
  - EcoBoost III
    - Multi-stage Boosting
    - Un-throttled