What's all this Skyactiv nonsense anyway?
Our Task

30% better fuel economy by 2015 (vs. 2008)

Option 1: Bet on hybrids

Option 2: Bet on electric

Option 3: Improve every car we sell
Development starts with a clean slate
<table>
<thead>
<tr>
<th>Contributors to 30% improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Engine</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Transmission</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Weight Reduction</strong></td>
</tr>
<tr>
<td><strong>Synergies, model substitution and nit picking</strong></td>
</tr>
<tr>
<td><strong>Total</strong></td>
</tr>
</tbody>
</table>
Each new model will be at least 100kg lighter than its predecessor

Development targets
- Increase rigidity 30%
- Reduce weight 8%
- Top crash safety performance

Weight loss strategy
- Efficient structure
- High-tensile steel (no exotic materials yet)
- Common body structure concept across many models
Stricter frame and multiple load paths

Previous

SKYACTIV-body

Bent Frame

Straight frame

Inefficient load path

Continuity

Broken load path
Corners of a box section are the strongest parts, so 12-point box shape offers “free” strength improvement.

Front Crossmember
- Weight: -6.4kg (14.1lb)
- Rigidity: 140%

Rear Crossmember
- Weight: -4.5kg (9.9lb)
- Rigidity: 100%

Spot welds replaced with MIG welds
Rigidity enhanced by removing flange

Current

SKYACTIV
- Targeted use of high-tensile steels gives high strength with low weight.
- Industry first use of 1800 MPa ultra-high tensile steel (in bumpers.)
- 61% of total body weight is some form of high-tensile steel.
### Redefining platform flexibility

**Fixed:**

- **Structural concept (continuous load paths)**
  - Frame cross sections
  - Joining structures and methods
  - Fixturing method and assembly sequence

**Variable:**

- **Floor Height**
- **Wheelbase**
- **Overhang**
- **Track width**

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1. **CD-car**
2. **C-car**
3. **C-SUV**
4. **CD-SUV**

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*Images of car models are shown.*

*Text in Japanese is translated as follows:*

- **FRAMES**
  - B FRAME
  - FR.FRAME
  - Rear frame

- **CROSSES**
  - No.3 CROSS
  - No.4 CROSS
  - No.4, 5 CROSS
Skyactiv Weight loss record so far

- Lightest CX-5 vs lightest CX-7: -130 kg (-288 lbs)
- Heaviest CX-5 vs Heaviest CX-7: -261 kg (-575 lbs)
There are still huge opportunities for improved efficiency from gasoline engines.

Opportunities for improved efficiency

- Capture more combustion energy
- Lose less of that energy

Skyactiv-G engine

Ideal combustion + mechanical efficiency

Heat Energy Balance (%)

0 20 40 60 80 100

Engine Load (%)

0 20 40 60 80 100

Radiation, Misfiring Loss

Exhaust Loss

Cooling Loss

Mechanical Loss

Pumping Loss

Actually moving the car
Higher expansion ratio (and compression ratio) is key factor in capturing combustion energy.

Achieving those theoretical gains requires deep study of combustion fundamentals.
Knock is uncontrolled combustion self-ignited by the heat and pressure of high compression.

The Mazda Solutions

- Lower the temperature before combustion
- Faster combustion so there’s less time for knock to develop
Advanced Direct Injection

Higher injection pressure (2,900 psi,) up from 1,600 on previous DISI engine, and 43 on port injected engines

Multi-injection strategy

6-hole injection pattern for optimum fuel distribution

Spray-guided tumble flow of intake air
Problem: Flame kernel contacts the piston, causing cooling loss and slowing combustion (which increases chance of knock)

Solution: Combustion pocket

Skyactiv-G engine Pursuing Ideal combustion
**4-2-1 Exhaust Manifold:**
Tuned exhaust manifold is as important as advanced direct injection and volcano-top piston combined.

**Compression with 87 AKI fuel:**

<table>
<thead>
<tr>
<th>Conventional manifold</th>
<th>4-2-1 manifold</th>
</tr>
</thead>
<tbody>
<tr>
<td>12:1</td>
<td>13:1</td>
</tr>
</tbody>
</table>

(Mazda3) (CX-5)

Packaging requires coordination with **SKYACTIV-BODY**
New idea? Not really...
All race engines use this idea.
But this manifold puts the catalyst too far away, so it takes too long to heat up.
But we did it...

The Mazda Solutions
- Advanced DISI and combustion pocket create stable, stratified charge.
- Stable combustion allows retarded ignition that doubles exhaust temperature
Capture more energy from combustion

Lose less energy on the way to the wheels

Radiation, Misfiring Loss

Exhaust Loss

Cooling Loss

Mechanical Loss

Pumping Loss

Effective Output

Engine Load (%)

Skyactiv-G engine  Pursuing Mechanical Efficiency
Friction reduction through the “gram strategy” approach

- 74% less oil pump drag
- 31% less water pump drag
- 25% less reciprocating drag
- 50% less valvetrain friction
- 27% less belt drive drag
- 20% less pumping loss
Intake valve timing is controlled over a 70-degree range to allow seamless switching between conventional and open-throttle Miller Cycle operation.

Leaving the intake valve open late is more efficient than closing the throttle. *Pumping loss reduced by 20%*
Brake Specific Fuel Consumption matches conventional Diesels

*Figures vary a few percent in N. American spec (87AKI).*
Skyactiv-G *can scale from 1.3 to 2.5 liters*

### Fixed elements:
- Combustion concept
- Interfaces (bellhousing, accessory mounts)
- Basic structure (open deck, split crankcase)
- Fixturing method and assembly sequence

### Variable elements:
- Bore x Stroke
- Bore Spacing
- Engine length and height
- Crank pin dimensions

<table>
<thead>
<tr>
<th>MZR L-series 2.0L</th>
<th>MZR Z-series 1.3L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed deck</td>
<td>Open deck</td>
</tr>
<tr>
<td>Bearing ladder</td>
<td>Split Crankcase</td>
</tr>
</tbody>
</table>

Skyactiv-G 2.0L  
Skyactiv-G 1.3L  
Same structure, different size
Common combustion character simplifies calibration

Different combustion characteristics for each engine family

- Z-series MZR (1.3-1.5L)
- L-series MZR (1.8-2.5L)
- L-series MZR with DI
- L-series MZR with DI + Turbo

**Result:** huge engineering commitment to maintain over 177 different engine calibrations

**SKYACTIV-G engines**

Similar combustion characteristics for all displacements

Scalable design from 1.3-2.5L

**Result:** dramatically reduced development and calibration expense
Old single-purpose machining process

Gasoline engine I4
Small

Gasoline engine V6
Mid-size

Diesel engine I4 mid-size

45 total machining processes

New CNC machining process

Gasoline engine I4
Compact, mid-size

Diesel engine I4 mid-size
V6

① ② ③ ④

4 machining processes

Capital investment reduced 70%

I4, V6 (current 3.7L), Gasoline and Diesel engines machined and assembled on one mixed line

Flexibility to respond to unexpected demand (eg: Diesel in Japan is 500% over plan)
Development Targets:

- 20% better fuel economy (vs. current Diesel)
- More low-rpm torque and more high-rpm flexibility
- Meet emissions standards around the world without expensive urea injection
- Lower cost than Hybrids
The Diesel emissions challenge

- Lean combustion causes NOx
- Most NOx countermeasures cause soot
- Urea injection fixes NOx, but is expensive, inconvenient
Diesel ignition occurs before the fuel is sufficiently mixed. Local hot spots cause NOx and over-rich spots cause soot.
Skyactiv-D

(Low Compression)

Low Compression Temperature

Better mixing = cleaner emissions

Fuel Spray Photograph

Becomes leaner with time

High-compression combustion

Skyactiv-D combustion

Lower compression gives more time to mix before ignition.
The result is clean combustion with low NOx and soot emissions
Advantages of Skyactiv-D

- Decreased compression temperature and pressure
- More time available to form ideal mixture prior to ignition
- Clean combustion with reduced NOx and soot emissions

Drawbacks to conventional diesels

- High compression causes ignition before the air-fuel mixture is ideal
- Local heterogeneous combustion
- NOx and soot are formed
Diezel engine breakthrough
The lowest compression ratio available for a diezel engine in a passenger car!
Enables ideal combustion timing
Low compression enables ideal combustion timing near the top of the piston stroke.

Higher expansion ratio improves power and fuel economy.

Benefits of SKYACTIV-D: 20% less fuel consumption and CO$_2$ emissions compared to its predecessor!
Ideal combustion timing

Conventional Diesel Engine (High Compression, Low Expansion)

SKYACTIV-D (Low Compression, High Expansion)
Low compression = lighter construction

- New block, crank, rods and pistons reduce engine weight by 10%
- Better handling

- Mechanical friction decreased to gasoline engine levels
- 5% Improvement in fuel economy
- Lively engine response and higher redline
Low compression makes cold starts difficult

- Solution #1: Intelligent, fast-acting ceramic glow plugs
Low compression makes cold starts difficult

- Solution #2: super-fast 12-hole piezo injectors
Low compression makes cold starts difficult

- Solution #3: Patented Variable Valve Lift strategy.
  
  - A special cold-start-only cam lobe briefly opens the exhaust valve during the intake stroke.
  - Hot exhaust gasses warm the intake charge for easier cold combustion.
Skyactiv-D

the cold start challenge

Series Sequential Twin Turbos
More low-rpm torque, more high-rpm power, more flexible, more fun

Skyactiv-D

Wide, flexible powerband

Torque improvement

Current Mazda 2.2L DE (US)

Torque (lb.-ft.)

Engine Speed (rpm)
Wide, flexible powerband
Skyactiv-D

Off-the-charts efficiency
The SKYACTIV engineering philosophy starts with a blank slate and an open mind.

Ideal Automatic Transmission

- High efficiency
- Direct, connected feel, like a manual transmission
- Quick & responsive shifting
- Smooth shifting
- Easy, intuitive low-speed control
- Smooth & powerful launch
## Survey of Existing Technologies

Nothing can achieve Mazda’s needs

<table>
<thead>
<tr>
<th>Feature</th>
<th>Dual Clutch</th>
<th>CVT</th>
<th>Conventional Torque Converter</th>
<th>Mazda Ideal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low-speed</td>
<td>✔</td>
<td>✔</td>
<td>✗</td>
<td>✔</td>
</tr>
<tr>
<td>High-speed</td>
<td>✔</td>
<td>✗</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Direct, connected feel</td>
<td>✔</td>
<td>✗</td>
<td>✗</td>
<td>✔</td>
</tr>
<tr>
<td>Quick, responsive shifting</td>
<td>✔</td>
<td>✗</td>
<td>✗</td>
<td>✔</td>
</tr>
<tr>
<td>Smooth shifting</td>
<td>✔</td>
<td>✔</td>
<td>✗</td>
<td>✔</td>
</tr>
<tr>
<td>Easy low-speed control</td>
<td>✗</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Smooth, powerful launch</td>
<td>✗</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
</table>
Conventional automatic problems:

- Torque converter slip
- Indirect feel - no connection
- Slow shifting
- Rough downshifts

Mazda’s solution:

- Use both torque converter and clutch, depending on the situation.
- Redesign Hydraulic Control for quick shifting
Clutch and torque converter together

- Direct, connected feeling
- 7% better fuel economy
- Quiet and smooth

SKYACTIV-Drive torque converter/clutch assembly

- Smaller torus only operates under 5mph
- Larger, multi-plate clutch for more precise control
- Larger damper to cancel vibrations caused by new low rpm, high load conditions
Multi-plate clutch + torque converter
Torque converter slippage delays acceleration response to driver’s input.

Current Automatic Transmission

- **Throttle position**
  - 0: Pedal is not depressed
  - 50: Pedal is halfway depressed
  - 100: Pedal is fully depressed

- **Gear Position**
  - 3: 3rd gear

- **Engine speed**
  - RPM Flares (Torque converter slips)

- **Vehicle speed**
  - Vehicle starts accelerating

**Delay**

**Time →**
Locked-up clutch provides direct, immediate response.
Benefits

- 7% better fuel economy
- More efficient than Dual Clutch or CVT
The problem:
Tolerance stackup makes transmission response inconsistent.
The resulting shifts are slow and not smooth enough.

The solution:
Gram-strategy approach to eliminate delay and imprecision from every part.
Mechatronic module that’s individually calibrated to compensate for production tolerances.

The Result
Perfectly rev-matched downshifts and smooth, seamless upshifts
Faster downshift response to gas pedal input
A drivetrain that responds to the driver’s needs almost telepathically
**Shorter shift response time**

Faster downshifting than a dual clutch transmission

**The Mazda solution**

New mechatronic module controls the gear change process

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<table>
<thead>
<tr>
<th>Gear</th>
<th>Speed</th>
<th>Shift response time (sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-&gt;2</td>
<td>50 mph</td>
<td>0.05</td>
</tr>
<tr>
<td>6-&gt;3</td>
<td>60 mph</td>
<td>0.10</td>
</tr>
<tr>
<td>5-&gt;4</td>
<td>45 mph</td>
<td>0.15</td>
</tr>
<tr>
<td>6-&gt;5</td>
<td>70 mph</td>
<td>0.20</td>
</tr>
</tbody>
</table>

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**SKYACTIV Drive**

- 5->2: 50 mph
- 6->3: 60 mph
- 5->4: 45 mph
- 6->5: 70 mph

**EU-A Dual Clutch Transmission**

- 5->2: 50 mph
- 6->3: 60 mph
- 5->4: 45 mph
- 6->5: 70 mph

The Mazda way: Smooth & quick shifting
Recap: how we did it

Target
- High efficiency
- Direct, connected feel, like a manual transmission
- Quick & responsive shifting
- Smooth shifting
- Easy, intuitive low-speed control
- Smooth & powerful launch

How SKYACTIV-DRIVE does it
- Eliminate torque converter slippage above 5 mph
- Mechatronic module and high-speed communication between engine and trans
- Still using the torque converter for what it does best.
Development targets

- Light and direct shift feel, like the MX-5 Miata
- Light weight and compact size
- Better fuel economy
The Mazda solution:

- Everything! Every part redesigned for light effort and short travel.
  - Internal shift travel shortened 15%
  - Low-effort locking ball synchro
  - Linear ball bearings
  - Gravity-assisted shift mechanism
  - Low-friction detent mechanism

The Problem:

- Shorter shift throws = heavier shift throws. Its simple leverage
The Result

Shift stroke is the shortest of any competitive passenger car, and lighter than most.
Transmission efficiency
Both SKYACTIV-MT versions achieve best-in-class performance

Torque capacity vs. weight
SKYACTIV-MT combines high torque capacity with minimized weight
Reduced Friction

- Lower-viscosity oil (75W-90 to 75W-80)
- Ball bearings replace tapered roller bearings
- Oil distribution system reduces fluid stirring losses.