TECHNICAL BRIEF NO. 3 | OCTOBER 2016

SERIES: U.S. PASSENGER VEHICLE TECHNOLOGY TRENDS

Transmissions

In the technology analyses for the 2025 corporate average fuel economy (CAFE) and greenhouse gas standards, the National Highway Traffic Safety Administration (NHTSA) and the U.S. Environmental Protection Agency (EPA) projected that advancements in transmissions would be a significant part of the technological improvements needed to meet the standards. By 2025, dual-clutch automated manual transmissions (DCTs) were projected to comprise 56% of the fleet and, compared to a conventional 4-speed automatic, improve efficiency by 9.7% to 12.6% at a cost decrease of $24. Conventional automatic transmissions (ATs) with eight speeds and higher efficiency were projected to comprise 35% of the fleet and increase vehicle efficiency by 6.5% to 7.8% at a cost increase of $36. The projections assumed that continuously variable transmissions (CVTs) would be completely replaced by DCTs or ATs by 2025.

Since their analyses were completed in 2012, conventional automatic transmissions and CVTs have improved beyond the agencies' projections, while use of DCTs has been less widespread than anticipated because of early problems with consumer acceptance. Conventional automatics have pushed beyond estimated efficiency gains for 2025, with the introduction of 9-speed and 10-speed designs and mechanical dog-clutches to reduce internal friction. Certain long-standing design issues with CVTs have been resolved and newer CVTs have reduced internal friction, wider ratio spread, and increased torque capacity. As a result, CVT market share has exploded, from 9% in 2012 to 18% in 2015. CVTs have efficiency similar to conventional automatics, and are cheaper than either conventional automatics or DCTs. Both conventional automatics and CVTs are smaller and lighter than DCTs, making them easier to package and offering modest secondary weight reductions.

Figure 1 compares the estimates of transmission efficiency, cost, and market penetration in the rule to updated assessments based upon work by researchers from the ICCT and Dana Corporation.[1] Assuming 2025 will have roughly a one-third share for each of the transmission types, the average efficiency and average cost in 2025 will be similar to the projections in the rulemaking (efficiency 0.5% to 0.8% lower, costs $20 less to $12 more). This does not factor in the potential for further innovation, such as the VariGlide Planetary Variator, which could improve efficiency, reduce cost, and extend durability.

1 Aaron Isenstadt, John German, Mark Burd, and Ed Greif, "Transmissions," ICCT working paper 2016-17 (2016), http://www.theicct.org/PV-technology-transmissions-201608.

ABOUT THIS SERIES Under efficiency standards adopted in 2012, the U.S. passenger vehicle fleet must achieve an average fuel economy of 49.1 miles per gallon in 2025, or 54.5 mpg as measured in terms of carbon dioxide emissions with various credits for additional climate benefits factored in. While the fleet-average targets may change—the regulation provides for recalculating the fuel economy targets annually based on the mix of cars, pickups, and SUVs actually sold—they will still represent an average energy-efficiency improvement of 4.1% per year.

Automakers have responded by developing fuel-saving technologies even more rapidly and at lower cost than the U.S. EPA and NHTSA projected in 2011–2012, when the supporting analyses for the 2017–2025 rule were developed. In particular, innovations in conventional (as opposed to hybrid or electric) powertrains and vehicle body design are significantly outpacing initial expectations. These technical briefs highlight the most important innovations and trends in those conventional automotive technologies.

For other papers in this series, as well as the more detailed technology surveys on which these briefs are based, go to www.theicct.org/series/us-passenger-vehicle-technology-trends.

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THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

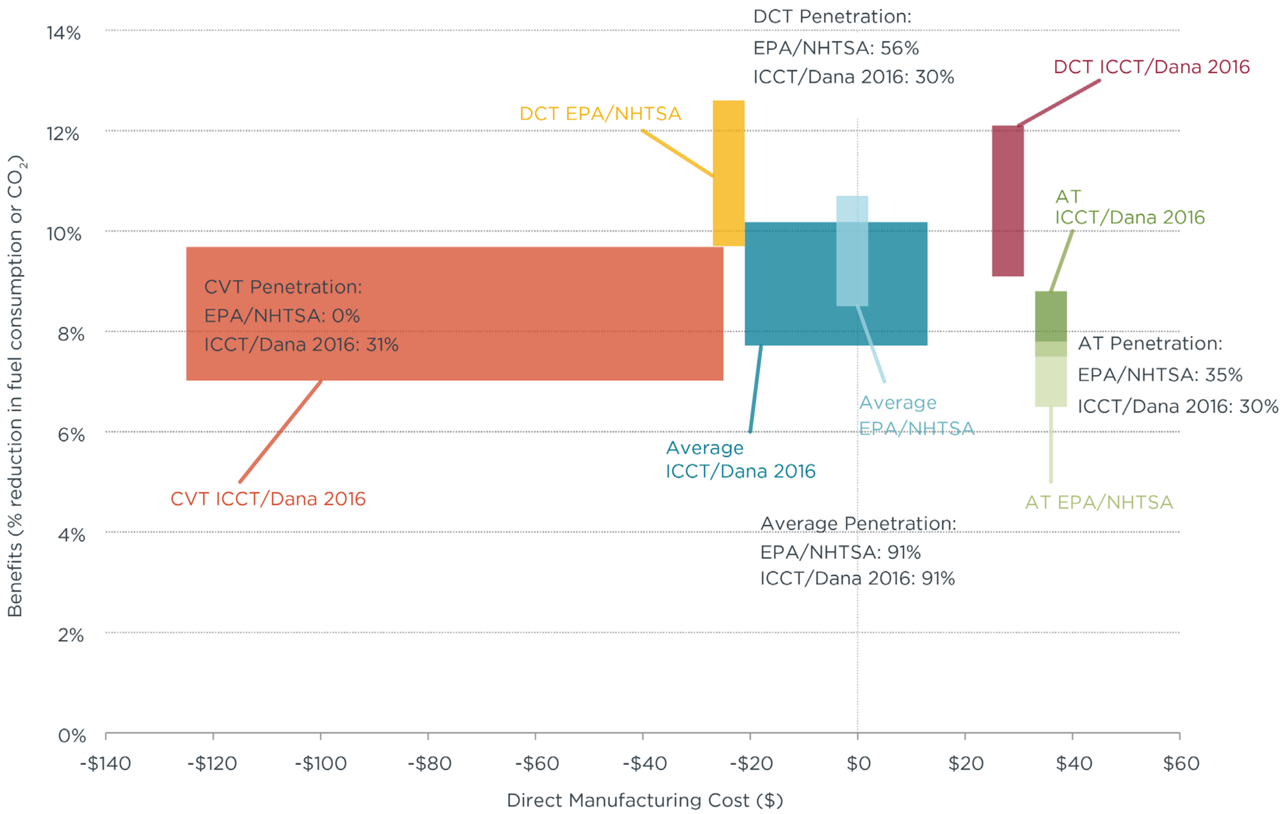

Figure 1. Market penetration, efficiency, and cost compared to baseline 4-speed conventional automatic, (Source: EPA/NHTSA technology analyses for 2025 CAFE/GHG standard rulemaking and ICCT/Dana 2016 update. Note that the 2025 rulemaking technology analyses did not assess CVT cost.)

TRANSMISSIONS DESIGN AND IMPROVEMENTS

Cars and light trucks need transmissions because the internal combustion engine provides usable power only within a limited engine speed (roughly 1500 to 6000 rpm). Thus, transmissions have important impacts on vehicle efficiency, performance, and drivability. In general, engine efficiency is highest at lower engine speed (which minimizes engine friction) and higher output per cylinder combustion event (which increases the proportion of energy used to propel the vehicle, instead of being lost to heat or forcing air into the engine). The acceleration rate increases with both higher engine speeds and cylinder output. Thus, for best efficiency it is desirable to have the transmission in the highest gear possible, while for acceleration the transmission needs to downshift into lower gears. More gears allow better matching to desired efficiency and performance. A wider range of gears allows better acceleration from a start and lower engine speed on the highway, for better efficiency and lower engine noise. Frequent transmission “hunting” for the right gear is a major source of consumer complaints.

Transmissions also include devices to “slip” the connection from the engine, in order to create smooth shifts and a smooth launch.

There are four basic transmission types that were well known and analyzed in 2012 by NHTSA and EPA for the 2017–2025 rulemaking:

- Manual transmission (MT), with a dry clutch operated by the driver;
- Automatic transmission (AT), using hydraulic clutches and gears;
- Dual-clutch automatic transmission (DCT), which operates similarly to a manual transmission except under computer control; and
- Continuously variable transmissions (CVT), which use cones connected by a belt to offer a continuous range of effective gear ratios.

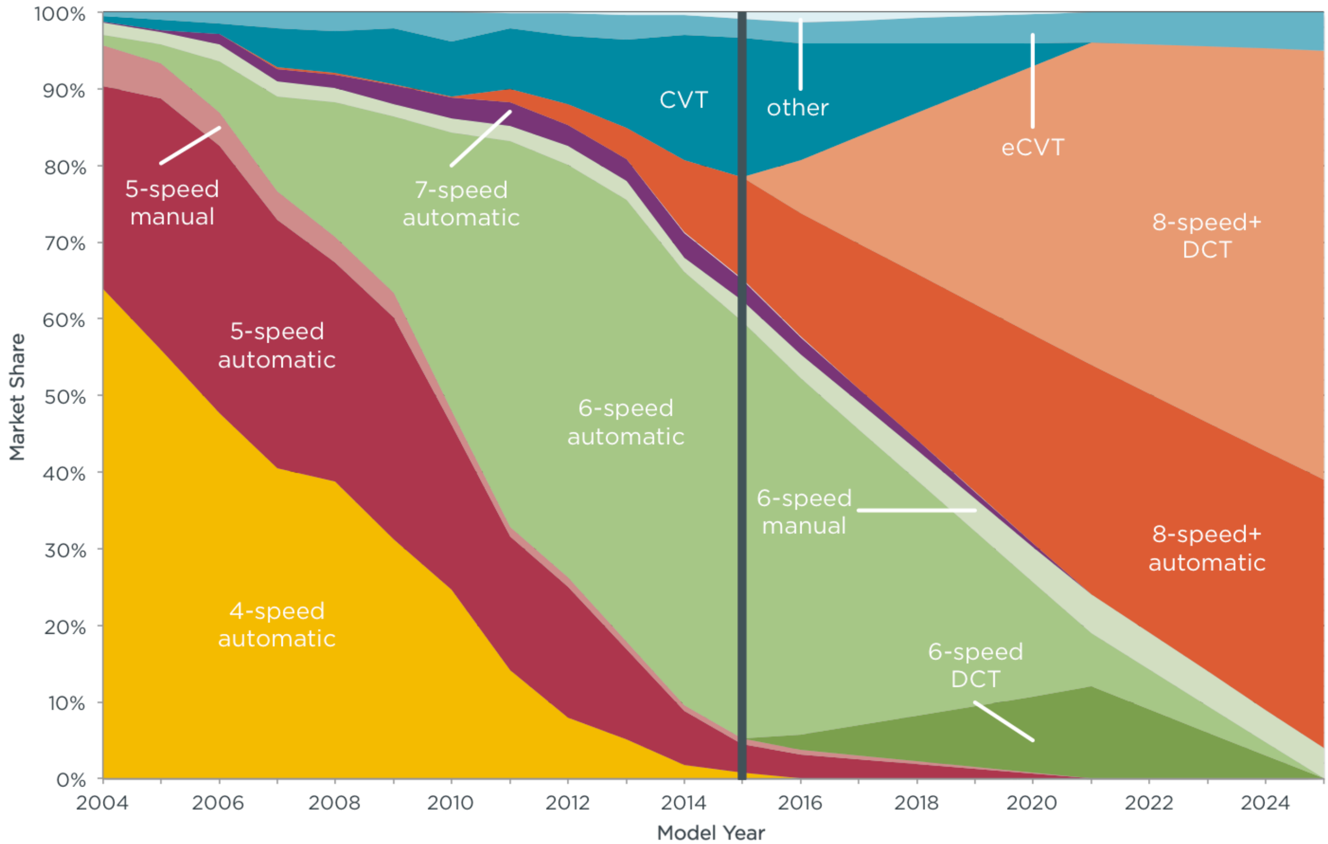

Figure 2. Historical and predicted market share of various transmissions by type and number of gear ratios.

These transmissions compete with each other in the market. All are being continuously improved by incremental design changes, such as adding additional gear ratios, widening the gear ratio spread, and reducing energy losses inside the transmission. The only genuinely revolutionary design presently in active research and development is the Dana VariGlide, which operates like a toroidal CVT and whose market penetration in the future is uncertain. (See sidebar.)

As shown in figure 2, to the left of the vertical line, the market is still dominated by conventional automatics. Increasing the number of gear ratios on these ATs has been very well received, as this improves efficiency, increases performance, reduces gear "hunting," and reduces engine noise on the highway. Thanks to innovations in configuring transmission gears, increasing the number of gears is also inexpensive.

The right side of figure 2 shows the projected market share through 2025 from the 2017–2025 rulemaking. By 2025, the agencies projected that all transmissions would have eight speeds and the market would be dominated by DCTs (56%) and conventional automatics (35%), with no conventional CVTs left in the market. This projection was primarily based on forecasts that DCTs would be both more efficient and cheaper than conventional automatic transmissions, as well as an implicit assumption that CVTs would not improve significantly.

CONTINUOUSLY VARIABLE TRANSMISSIONS

After years of incremental development to overcome challenges inherent to their design (shown schematically in figure 3), CVTs offer a real alternative to traditional automatics. Increased hydraulic pressure squeezing the pulleys and improved belts have vastly expanded the torque range and gear ratio spread. Engine-efficiency benefits achieved now offset losses associated with high-pressure pumps and friction, for net efficiency gains. The CVT is an inherently lower-cost design, and suppliers have managed to keep costs low enough that CVT sales are increasing rapidly. Continued development will further reduce losses and cost.

Their eventual cost and market share, especially compared to DCTs, will depend on the degree to which energy losses can be minimized and on improvements in cost and consumer acceptance of DCTs.

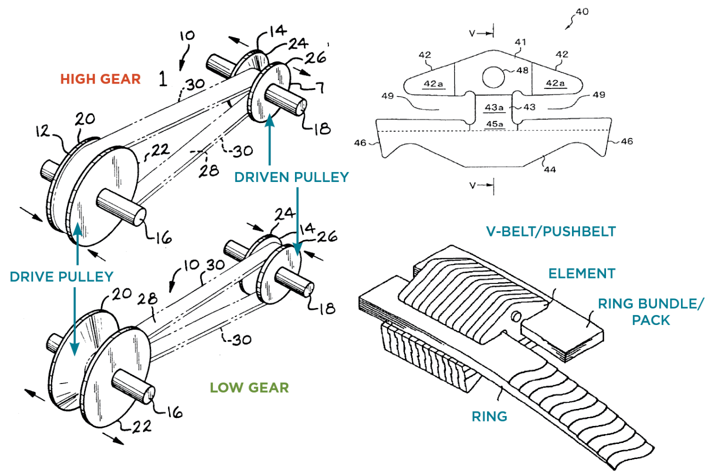

Figure 3. Schematic diagram of CVT conical pulleys and laminated steel belt.

DUAL-CLUTCH TRANSMISSIONS

DCTs have not taken off in the U.S. as forecast. This is likely attributable to issues with launch and shift feel that have put some consumers off, and to difficulty in finding space for the larger girth of this transmission. The consumer acceptance issues may eventually be addressed by hydraulic clutches, which also feature higher torque capacity. Today, hydraulic-clutch DCTs approach the efficiency of friction clutches, albeit at a small efficiency penalty and an additional cost of about $50.

CONVENTIONAL AUTOMATIC TRANSMISSIONS

Incremental improvements in automatics with eight gear ratios have led to efficiencies roughly on par with rulemaking predictions for that specific design. However, there have been two significant efficiency improvements since the analyses in the rulemaking. First, 9-speed and 10-speed automatics have already been introduced, which the rulemaking analyses did not project, and these feature incremental efficiency improvements over the 8-speed transmission modeled for the rulemaking. In addition, faster on-board computers, which permit better shift calibration, allow friction clutches to be replaced with more efficient mechanical clutches, as on the new ZF 9-speed transmission used on the Acura MDX, Chrysler Pacifica, Honda Pilot, Jeep Cherokee and Renegade, and others.

It appears that manufacturers may be sticking to the transmissions they know best. Most vehicles in Europe still use manual transmissions. DCTs, which are simply manual transmissions shifted automatically, are widely used by European manufacturers in the United States, and that customer segment seems to accept them. CVTs excel in the low-speed congested conditions that dominate driving in Japan. As CVTs have improved to handle higher torque, expand the ratio spread for better highway fuel economy, and improve shift logic to recreate some of the shifting experience of driving an automatic on a CVT, Japanese manufacturers have largely replaced conventional automatics with CVTs in the United States. The U.S. manufacturers are experimenting with both CVTs and DCTs, but have also tended to fall back on their long-standing expertise in conventional automatics. Both manufacturing history and consumer history with the feel of a torque converter favor conventional automatics for the U.S. manufacturers.

IMPLICATIONS FOR THE MIDTERM EVALUATION

Unanticipated improvements in the design of conventional automatic transmissions and CVTs are offsetting the slower than projected deployment of DCTs in the U.S. passenger vehicle fleet, in terms of the general implications for improving fuel efficiency. As a result, the overall technology projections made for the 2017–2025 rulemaking concerning transmission efficiency and costs appear to be roughly on track.

Conventional automatics, in general, are matching the predicted cost and likely exceeding the projected benefit, due to the introduction of 9-speed and 10-speed transmissions and the increased efficiency of mechanical clutches. The growth in market share for higher speed automatics is strong, putting conventional transmissions on track to meet or exceed projections.

CVTs were not projected to be a competitive option by 2025. However, thanks to steady incremental design improvements, CVT market share doubled from 2012 to 2015. Although the agencies did not explicitly predict the costs of CVTs in the rulemaking, CVTs today appear to be on track to exceed the benefit estimates in rulemaking modeling and they cost less than conventional automatics. They will likely be strong competitors to DCTs and conventional ATs through at least 2025, especially for manufacturers with extensive CVT expertise.

While some of the technical challenges faced by DCTs are being resolved in new designs, the solutions will likely make them slightly more expensive and slightly less efficient than projected by the agencies. Although DCTs remain an attractive option in terms of comparative cost-effectiveness and efficiency, combined with improvements to CVTs and conventional transmissions, they are unlikely to match the penetration estimates in the rulemaking. Instead, the DCT future in the U.S. may be in high torque applications such as diesels and gasoline turbocharged engines.

Behind RM / On schedule / Ahead of RM	Manufacturing cost	Efficiency benefits	Market penetration
Dual-clutch transmissions	Behind RM	Behind RM	Behind RM
Conventional Automatics	On schedule	Ahead of RM	On schedule
Continuously variable transmissions	Ahead of RM	On schedule	Ahead of RM

Table 1. Transmission technology compared to EPA/NHTSA 2017-2025 rulemaking. Rapid improvements in continuously variable transmissions and conventional automatics have compensated for slower than projected growth in the use of dual-clutch automated manual transmissions

PLANETARY CVT

» VariGlide planetary variator technology is a traction drive employing rotating planets that tilt on their axes to vary the drive ratio, in place of the belt and concentric cones of a CVT. As shown in figure 4, by changing the angle of tilt of each planet's axis of rotation, the contact radii ratio changes, and therefore the speed ratio may be continuously varied as the transmission is shifted through the ratio range. While the production capability has yet to be proven, the design has a number of potential benefits over belt CVTs. It uses roller bearings instead of a belt to transmit loads, which should be more durable. These bearings also eliminate the need for a high-pressure pump, which contributes to some of the efficiency benefits over belt CVTs. The planetary CVT can handle higher torque than belt CVTs and the same design can be used in both FWD and RWD applications.

» Development testing has shown a 5% to 10% fuel economy improvement relative to modern 6-speed automatics. It also has improvements relative to current best-in-class belt CVTs.

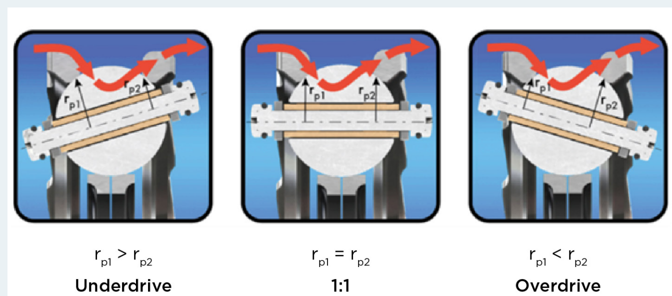

Figure 4. Shifting gears on the continuously variable planetary variator.