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Opportunities to Improve Tire Energy Efficiency

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EXECUTIVE SUMMARY

Tires are an important factor in passenger vehicle energy use. Globally, improvements in tire energy efficiency that lie well within existing capabilities could reduce fuel consumption by 3 to 5% across existing passenger vehicle fleets. The result would be a global reduction in greenhouse gas emissions by more than 100 million metric tons annually. These benefits can be achieved at relatively low cost through the design and sale of more efficient tires, which can be produced without sacrificing safety or other important design attributes. In addition, optimal tire efficiency requires proper maintenance—especially the maintenance of correct tire inflation, which affects rolling resistance. However, consumers are inadequately informed about how to improve or maintain the tire efficiency of their vehicles. Table ES-1 shows the current status of programs to overcome these obstacles in different parts of the world.

Table ES-1. Summary of tire standards, rating/labeling, and inflation programs.

COUNTRY/ REGION	TIRE STANDARDS	TIRE RATING/LABELING	TIRE INFLATION PROGRAM(S)
China	N/A	N/A	Voluntary tire pressure monitoring system (TPMS) standard drafted with 25% underinflation detection threshold
European Union	Mandatory standards will begin November 2012 for efficiency, wet grip, and noise	Mandatory program will begin November 2012 for efficiency, wet grip, and noise	Mandatory TPMS standard with phase-in beginning in 2012; detection threshold initially set at 20% with second-stage threshold of 15% under consideration
Japan	N/A	Voluntary program began January 2010 for efficiency and wet grip	Standards under consideration
South Korea	Proposed standards for efficiency and wet grip would take effect in 2013	Program proposed for efficiency and wet grip would take effect on a voluntary basis in 2011 and become mandatory in 2012	Mandatory TPMS standards proposed in 2010
United States	Potential California standards	Test method adopted in 2010; rating and labeling program for efficiency, wet traction, and durability likely delayed until at least 2012	Mandatory TPMS standards with underinflation detection threshold of 25% currently required for all new passenger vehicles; California automotive service provider tire inflation regulation effective as of 2010

Best Practice Recommendations

Several countries and regions have implemented or are in the process of implementing programs to improve tire efficiency and safety. Although additional experience will, of course, provide a basis for more complete and thorough analysis, experience to date supports the following best practice recommendations:

- **Tire efficiency ratings.** Rating and labeling programs are an important first step in improving tire efficiency because they encourage consumers to select, and retailers and manufacturers to offer, more efficient tires. The most effective programs will provide efficiency information to consumers in multiple ways that are easy to understand.
- **Tire efficiency standards.** Just as programs to improve the efficiency of replacement tires can benefit from the "pull" created by rating/labeling and consumer education to encourage top performance, minimum standards can create a "push" to raise the floor. This is a common model for many types of other consumer products, as information programs alone may not be effective for all consumers and/or may not completely overcome the market barriers to more efficient products. Verifiable testing data that are available to government regulators will enhance the accuracy and credibility of tire ratings and compliance with standards.
- **Comprehensive regulation.** The ICCT recommends that tire efficiency programs include a safety component to ensure that current levels are maintained and to achieve improvements where feasible. The ICCT also recommends providing consumers with information that encourages treadwear improvement to reduce tire disposal rates and potentially reduce particulate emissions from tire wear. Programs to encourage low rolling resistance may also lead to reductions in tire noise, given that the process of redesigning tires to decrease rolling resistance may also offer design opportunities to reduce noise.
- **Proper inflation.** Proper tire inflation is another important method for achieving safety, environmental, and economic benefits. Standards requiring the installation of tire pressure monitoring systems (TPMSs) as a safety and efficiency measure are an effective strategy, aided by the global spread of the technology. Consumer education programs and automotive service "check and inflate" programs are complementary options that will continue to provide benefits even in areas where TPMSs are implemented. Both types of programs will improve safety and will reduce the number of tires that wear out early because they are underinflated.

TIRE EFFICIENCY

This paper is intended to inform policymakers and other stakeholders about the benefits of energy efficiency improvements for passenger vehicle tires, and about current policies designed to achieve those benefits in the European Union, the United States, Japan, and South Korea. These regions together represent a large proportion of global tire manufacturing and sales (Michelin, 2009), as indicated in Figures 1 and 2. Several countries and regions have adopted one or more programs to improve tire efficiency (i.e., tire energy efficiency), but no country or region has implemented a comprehensive program addressing all aspects of tire efficiency. As a result, there are opportunities for all countries to benefit from shared experience and lessons learned.

The following sections of this paper explain potential benefits and costs for improvements in tire energy efficiency, market barriers to these improvements, and relationships between tire energy efficiency and other tire attributes. Then the paper summarizes programs that have been adopted to improve efficiency and other benefits through manufacturing and sales of better tires, followed by a summary of programs to increase proper tire inflation. Finally, the paper provides best practice recommendations.

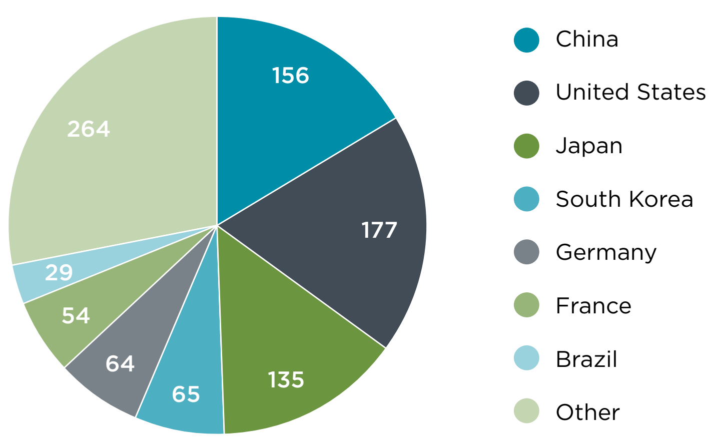


Figure 1. Global passenger vehicle tire manufacturing in 2006 (in millions). Data from Michelin (2009) and U.S. International Trade Commission (2009).

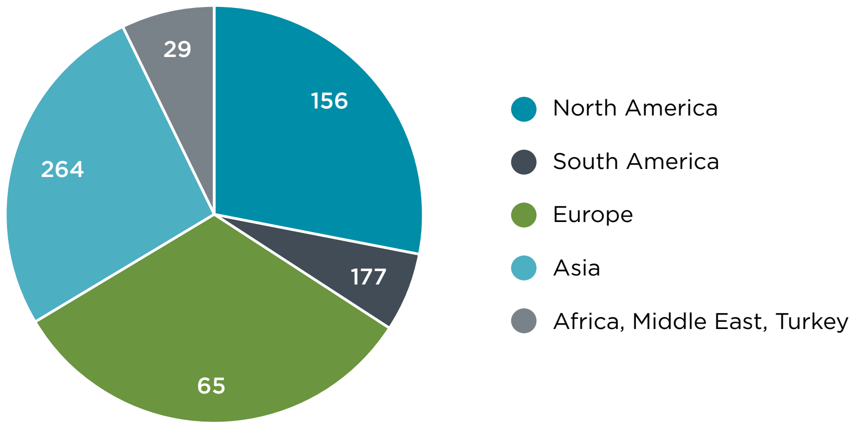


Figure 2. Global passenger vehicle tire market in 2008 (in millions). Data from Michelin (2009).

Benefits and Costs of Improved Tire Efficiency

The net energy output from the drivetrain of a passenger vehicle is used to overcome aerodynamic drag, rolling resistance, and braking losses. Energy use at the tires consumes about 20 to 30% of vehicle drivetrain net energy output (Commission of the European Communities, 2008a, p. 7). The U.S. National Academy of Sciences has estimated that net energy usage at the tires accounts for 5 to 7.4% of total energy loss for a passenger vehicle with an internal combustion engine (National Research Council, 2010). Rolling resistance is influenced by tire design and materials; underinflated tires have increased rolling resistance due to additional deformation. The amount of energy used at the tires to overcome rolling resistance is proportional to distance and load (i.e., vehicle weight) and is not expected to vary significantly on a per-mile basis with changes in speed.

Improved tire design and materials, as well as proper inflation and maintenance, will reduce the amount of energy used at the tires. Improving the rolling resistance of replacement tires by 10% will reduce fuel consumption by 1 to 2% (National Research Council, 2006) for a vehicle with replacement tires. The fuel consumption of a vehicle equipped with a tire pressure monitoring system (TPMS) meeting U.S. standards will be reduced by 0.5 to 0.7% relative to

ROLLING RESISTANCE

Rolling resistance occurs as tires deform during rotation. The portion of the tire that is deformed is subjected to compression, bending, and shearing forces within the rubber material that makes up the tire. Energy is used during these repeated deformations to overcome the viscosity of the rubber and is then dissipated in the form of heat as the tire returns to its original shape (Tonachel, 2004).

ROLLING RESISTANCE METRICS

"Rolling resistance can be expressed as a dimensionless coefficient (RRC), i.e. the amount of force generated given a certain weight on the tires. It can also be expressed as rolling resistance force (RRF) for a given expected weight on the tire" (Tonachel, 2004).

Both RRF and RRC can be measured using the same testing equipment. RRF is measured directly with a load applied to the tire consistent with the load that the tire is expected to carry in practice. The dimensionless RRC is calculated by dividing the rolling resistance force by the load that is applied to the tire during the test. The value of RRC thus derived can then be multiplied by a load factor to calculate how much energy is required to overcome rolling resistance at that load. RRC allows for the creation of a standard with a single metric across different tires designed for different loads, but its utility depends on the assumption that RRC is uniform and can be scaled across different loads.

a similar vehicle without such a system.[1] A European study projects reductions in fuel consumption of 3% from low-rolling-resistance tires and 2.5% from TPMSs that meet stricter standards than those set in the United States (Commission of the European Communities, 2008b, p. 20).

Widespread adoption of tire efficiency programs over the next decade that reduce vehicle fuel consumption by approximately 3% can reduce global well-to-wheels greenhouse gas emissions by 100 million metric tons per year in 2020.[2] This improvement would avoid the emission of more than 45,000 metric tons per year of nitrogen oxides and 10,000 metric tons per year of fine particulates from upstream fuel production and refining.[3] Potential annual fuel savings of 30 billion liters represent a cost savings of about $30 billion annually if refined oil prices average $1 per liter ($3.80 per gallon), thereby providing a substantial energy security benefit for oil-importing countries.

1 The National Research Council has estimated the fuel consumption reduction at 0.7% (U.S. NHTSA, 2010). The ICCT estimates the fuel consumption reduction at 0.5% on the basis of underinflation severity (6.8 psi for passenger vehicles, 8.7 psi for light trucks) and underinflation prevalence (26% for passenger vehicles, 29% for light trucks) (U.S. NHTSA, 2005, pp. V-54–V-55). The ICCT used data from the National Research Council (2006, p. 46) indicating that each 1 psi would lead to a 1.4% increase in rolling resistance, and estimates that each 3 psi underinflation would increase fuel consumption by 1%. The ICCT assumed that typical underinflation for the fleet would be about 3 psi and discounted the theoretical maximum benefits of TPMSs by assuming that tires flagged by a TPMS for gross underinflation would average 3 psi underinflation afterward.

2 This calculation is based on unpublished ICCT projections that global passenger vehicle CO_2 emissions would be approximately 3200 million metric tons in 2015 (on a well-to-wheels basis) and that fuel consumption would be 1000 billion liters of petroleum equivalent in 2015. For comparison, Michelin estimates that global use of low-rolling-resistance tires by itself would lead to a reduction of 80 million metric tons of CO_2 per year (Michelin, 2010).

3 These calculations are based on unpublished ICCT projections that global baseline 2015 emissions of NO_x would be approximately 1.5 million metric tons and that emissions of fine particulates (diameter 10 micrometers or less) would be approximately 350,000 metric tons. Note that vehicle-specific factors, such as engine and emissions control technology, may result in decreased on-the-road tailpipe emissions such as NO_x when engine load is reduced.

The costs of achieving these benefits appear reasonable at $10 or less per tire, despite some variations in cost estimates due in part to different improvement targets. The U.S. Environmental Protection Agency (U.S. EPA, 2010, pp. 1-8, 1-10) estimated the cost of improving rolling resistance for new vehicle tires by 10% (CO_2 reduction of 1 to 2%) at $6 per vehicle. A Commission of the European Communities staff document (2008a) estimated costs in the range of $10 per tire to both decrease rolling resistance by 25% and meet new European wet-grip standards.[4] National Research Council estimates range from a 2006 estimate of $1 per tire to decrease rolling resistance of replacement tires by increasing use of silica, to 2010 estimates of $2 to $5 per tire for new cars (with a $10 per tire upper estimate to reflect uncertainty). These estimates indicate that the incremental cost of lower-rolling-resistance tires would be repaid in about 14 months, even assuming the higher $10/tire estimate, in low-fuel-cost countries such as the United States, based on a fuel price of $1 per liter ($3.80 per gallon) and sooner for higher fuel costs.[5]

The cost of improving tire inflation also appears reasonable. A study for the Commission of the European Communities (2008b, p. 46) estimated the cost of a single TPMS at 3 euros (about $4) per year when spread over the vehicle lifetime; that is, the fuel savings would more than pay back the system's cost. The estimated economic benefits of California's automotive service provider manual inflation check program are several times the program's costs (California Air Resources Board [CARB], 2009a, pp. 32, 39).

Market Barriers to Improved Tire Efficiency

In the United States, when new passenger vehicles are tested for fuel economy and CO_2 emissions, they are equipped with the same tires sold on the vehicle. This creates an incentive for automakers to reduce tire rolling resistance for new vehicles and thereby maximize these test scores, which are used for advertising as well as regulatory compliance. The rolling resistance of tires on new cars in the United States decreased sharply during the 1980s and 1990s (Lutsey, 2006).

However, consumers lack information on energy efficiency and other characteristics of replacement tires. In addition, in some markets such as China and the European Union, the tires used for fuel economy testing may not be the same as the tires on new vehicles sold to individual consumers. Higher up-front costs and a lack of consumer information and education create a barrier to the sale of low-rolling-resistance tires in these cases. This also results in a disincentive for manufacturers to offer these more efficient tires.

4 The Commission of European Communities (2008a, table 7) listed a price of just over 8 euros, or $10, to reduce RRC from 0.12 to 0.09. Smokers et al. (2006) estimated significantly higher costs for low-rolling-resistance tires; on the other hand, a workshop conducted by the International Energy Agency (Meier et al., 2005) found that consumers would quickly realize savings that would pay back the additional costs of low-rolling-resistance tires.

5 This ICCT calculation for countries with lower fuel costs is based on 12,000 miles (19,300 km) per vehicle annually, 30 miles per gallon (12.7 km per liter), a fuel price of $3 per gallon ($0.80 per liter), and a 1.5% fuel savings with tire costs of $10 each.

Consumer education with respect to proper tire inflation is another market barrier. Consumers often do not know when and how to check the pressure of their tires (Rubber Association of Canada, 2010). New passenger cars are tested for fuel economy with tires properly inflated, so in the absence of standards, automakers will lack a strong incentive to sell vehicles equipped with TPMSs to improve inflation.

Relationship Between Tire Efficiency and Other Tire Characteristics

Existing tire efficiency programs also address safety and other tire characteristics. The following section discusses how safety, durability, and noise relate to tire efficiency. Other tire attributes, such as comfort, will be driven by marketability and consumer acceptance rather than government policy.

SAFETY

Safety has been included in all tire rolling resistance labeling programs and standards to encourage improvements and prevent the possibility of future backsliding. Traction or wet grip is widely used as an indicator of safety, despite the limitation that this metric does not address many real-world scenarios such as cornering. The question of whether manufacturers would trade off grip for rolling resistance in tire design deserves close attention, although this does not appear to be the case at present. The U.S. National Research Council (2006, p. 84) found substantial overlap for the rolling resistance of tires in each U.S. traction grade. Evaluation of California Energy Commission data shows that 90% of tires with above-average rolling resistance scores had an “A” traction rating, whereas 99% of tires with below-average rolling resistance scores had an “A” traction rating.[6] Similarly, research in the European Union did not find that tire manufacturers currently trade off between rolling resistance and wet grip (Commission of the European Communities, 2008b, p. 13; Smokers et al., 2006, p. 120).

Improved design and materials such as silica, as shown in Figure 3, can decrease rolling resistance without sacrificing traction. The goal is a tire that allows deflection to the extent required to maintain tire contact when hitting bumps in the road, while minimizing deformation to decrease rolling resistance when driving on smooth roads (Michelin, 2005; Tyres On-line, 2010).

Proper tire inflation represents another opportunity to improve tire efficiency and safety. U.S. TPMS requirements have reduced injuries and fatalities (National Research Council, 2006) while improving tire efficiency (see below). Other opportunities to improve inflation through manual pressure checks will similarly benefit both tire efficiency and safety.

6 CEC data sets available at www.energy.ca.gov/transportation/tire_efficiency/documents/index.html.

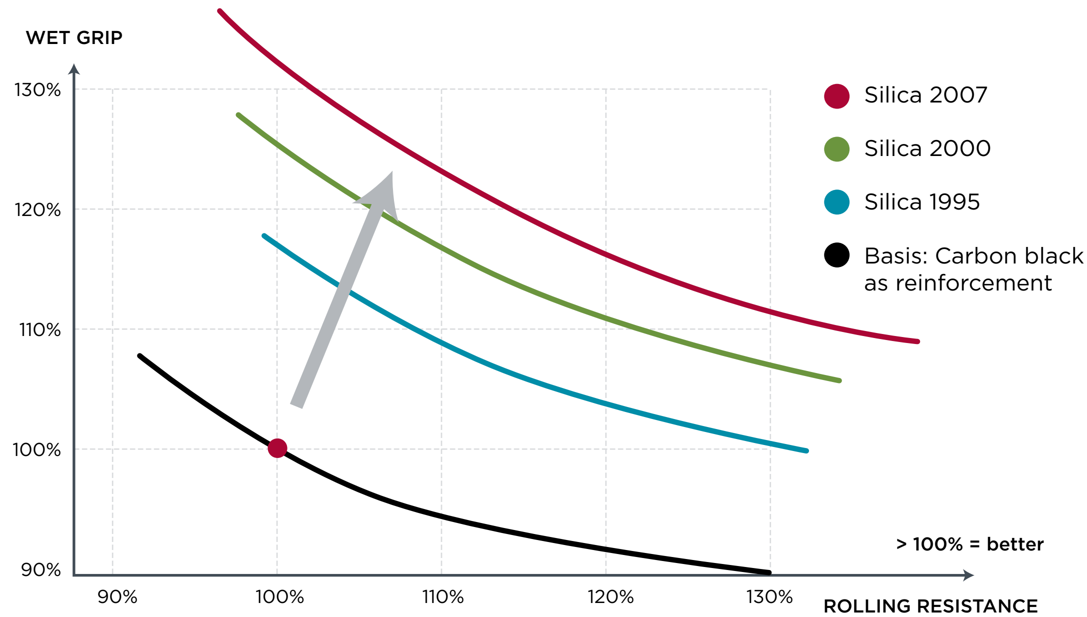


Figure 3. Wet grip versus rolling resistance.

Source: Continental Tyre Group AG.

DURABILITY

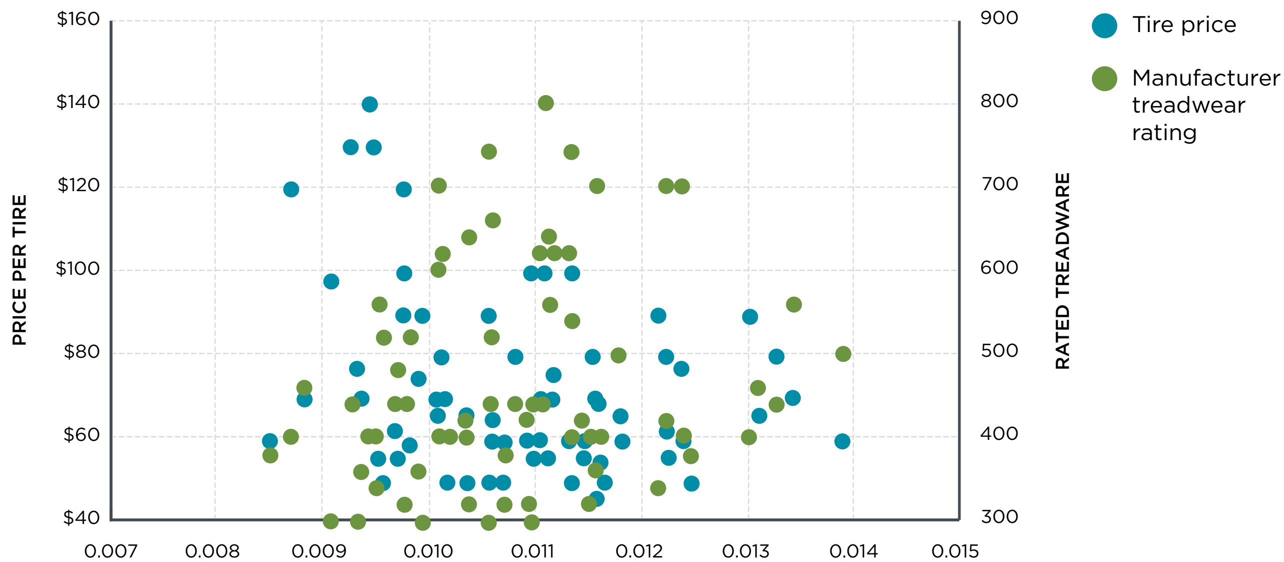
Programs aimed at improving tire rolling resistance should also prevent backsliding and seek improvements in tire durability to reduce the waste stream of discarded tires. Evaluation of test data from more than 600 tires, size 195 and 265, sold in California did not show any visible correlation between rolling resistance and manufacturer-stated treadwear (Fig. 4). Test specification JT 609 was used to measure these data. The National Research Council (2006, p. 92) and a report commissioned for the European Commission (Smokers et al., 2006, p. 120) similarly did not find any strong adverse correlation between rated tire wear and fuel efficiency. Tires with greater tread depth generally have greater rolling resistance due to the additional rubber and other material subject to deformation; tire wear leads to decreased rolling resistance. Tire manufactur-

FINE PARTICULATES AND TIRE WEAR

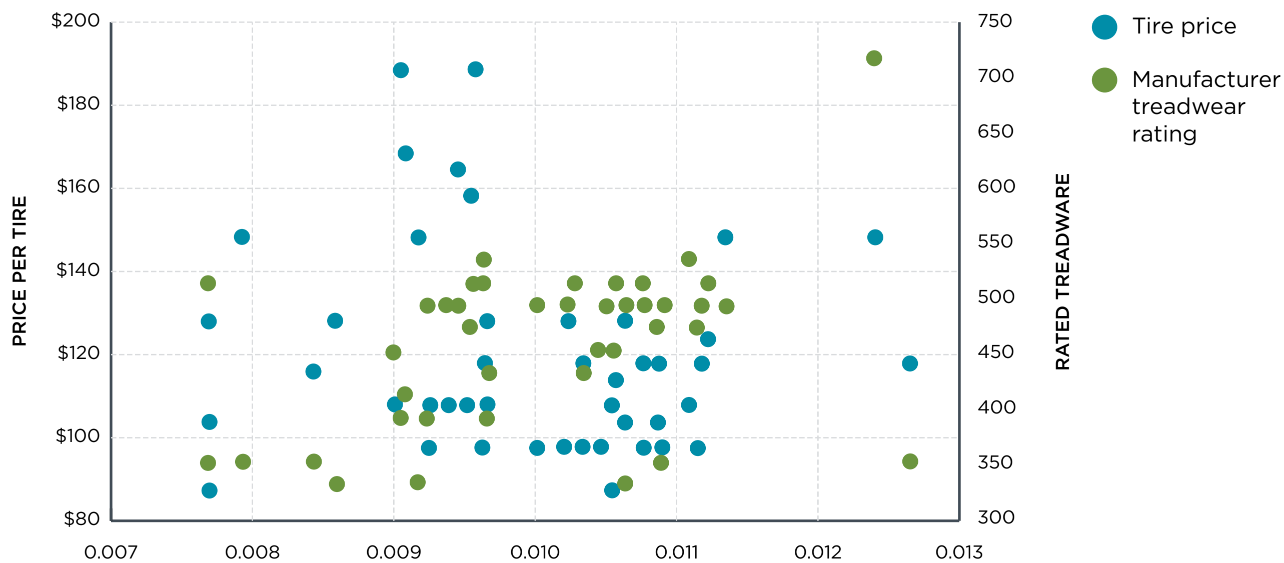
A tire manufacturers' study found that tire wear contributes 1 to 3% of ambient airborne particulates with diameters of 2.5 micrometers or less ($PM_{2.5}$) and 1 to 10% of particulates with diameters of 10 micrometers or less (PM_{10}) (ChemRisk, 2008). About one-quarter of California passenger vehicle PM_{10} emissions and 10% of $PM_{2.5}$ emissions during 2008 were attributed to tire wear (CARB, 2010) on the basis of estimated emissions of 0.008 g PM_{10} per mile and 0.002 g $PM_{2.5}$ per mile (CARB, 2000). Improved tire durability would potentially result in reduced emissions of these fine particulates, which in turn would lead to public health benefits.

ers could offer new tires with reduced tread depth, but any benefit from decreased rolling resistance would be offset by the need to replace tires more frequently.

Programs to promote proper tire inflation are an opportunity to improve tire efficiency and durability at the same time. Underinflated tires wear out more quickly and also have higher rolling resistance.



4A. Rolling resistance (tested using JT 609 at 895 lbs force)



4B. Rolling resistance (tested using JT 609 at 1775 lbs force)

Figure 4. Tire rolling resistance versus price and relative rated treadwear for (A) size 195 tires and (B) size 265 tires. Data from California Energy Commission (2010).

NOISE

The European Commission commissioned a study of the relationship between noise and other tire attributes. The study found no evidence of a significant relationship between tire noise and safety performance, nor between tire noise and rolling resistance. The study found that across all tire categories there is scope for a considerable reduction in tire noise limits, and estimated that the benefits of a 3 dBa noise reduction would exceed costs (Forum of European National Highway Research Laboratories, undated, p. 3).

Programs to Improve Tire Efficiency Through Manufacturing and Sale of Low-Rolling-Resistance Tires

The European Union, Japan, South Korea, and the United States have proposed or adopted programs to increase the manufacture and sale of passenger vehicle tires with decreased rolling resistance as well as improved grip and (in some cases) improved durability or reduced noise. These programs are summarized in Table 1 and described below. Although this paper focuses on passenger vehicles, it also includes some information on programs that cover medium and heavy-duty vehicle tires along with passenger vehicle tires.

Table 1. Tire efficiency and rating/labeling programs.

COUNTRY/REGION	MINIMUM STANDARDS	RATING AND LABELING
European Union	Mandatory standards will begin November 2012 for efficiency, wet grip, and noise	Mandatory program will begin November 2012 for efficiency, wet grip, and noise
Japan	N/A	Voluntary program implemented January 2010 for efficiency and wet grip
South Korea	Proposed standards for efficiency and wet grip would take effect in 2013	Proposed program for efficiency and wet grip for voluntary implementation in 2011 and mandatory implementation in 2012
United States	Potential California standards	Test method adopted in 2010; rating and labeling program for efficiency, wet traction, and durability likely delayed until at least 2012

EUROPEAN UNION

Standards. The European Union has established minimum standards for rolling resistance and wet grip for new tires (EC Regulation 661/2009; European

Parliament, 2009a) as summarized in Table 2.[7] The standards will apply to tires for new vehicles as well as replacement tires. The initial E.U. phase 1 standards essentially eliminate the lowest-efficiency tires on the market, which appear to constitute a small share of the market.[8] E.U. phase 2 will lower the ceiling for the rolling resistance coefficient (RRC) to 0.0105 dimensionless RRC (expressed as 10.5 kg/tonne in local regulations). According to current estimates, just less than half of projected 2015 market share would have exceeded this level without standards (Commission of the European Communities, 2008b, p. 44).

The phase-in schedule contains several milestones for both E.U. phase I and phase II standards. The first step for each phase applies to approvals for new models of tires, and then to tires installed on new models of cars. The next step for each phase is a sales ban on tires that do not meet the standards, but with a 30-month exemption for sell-off of existing stock [which can be reconsidered under EC Regulation 661/2009 Article 14(3)(b); European Parliament, 2009a]. Winter tires are subject to a slightly less strict standard (European Tyre and Rubber Manufacturers Association, 2010).

UNECE STANDARD

United Nations Economic Commission for Europe Regulation No. 117 on Tyre Rolling Noise, Wet Grip Adhesion and Rolling Resistance (April 9, 2010) is largely based on the E.U. standards. Individual countries could choose to adopt this standard at the national level. One difference from the E.U. standards is that each country adopting the U.N. regulation would need to affirmatively exercise the Article 12 authority to phase out tires that were previously approved but do not meet the minimum standards.

Table 2. European Union tire standards.

TIRE TYPE	PHASE-IN PERIOD		ROLLING RESISTANCE COEFFICIENT (dimensionless)		ROLLING RESISTANCE COEFFICIENT (kg/tonne)		NOISE AND WET GRIP
	Phase 1	Phase 2	Phase 1	Phase 2	Phase 1	Phase 2	
C1	Nov 2012–Nov 2014	Nov 2016–Nov 2018	0.0120	0.0105	12.0	10.5	70 to 74 dBA noise; wet grip index > 110% (except snow tires)
C2	Nov 2012–Nov 2014	Nov 2016–Nov 2018	0.0105	0.0090	10.5	9.0	72 to 75 dBA noise; wet grip pending test method
C3	Nov 2012–Nov 2016	Nov 2016–Nov 2020	0.0080	0.0065	8.0	6.5	

Tires for passenger and commercial vehicles 3500 kg or less are categorized as C1. Tires for buses and commercial vehicles are categorized as C2 if they are designed for a maximum load of 1450 kg per tire and a specific speed category, or as C3 if designed for a higher load or different speed category. Rolling resistance is measured according to ISO 28580.

7 The European Union has also adopted a standard for polycyclic aromatic hydrocarbons (PAHs) that became effective January 1, 2010 to protect human health and the environment (Directive 2005/69/EC). The European Union found that PAHs are a persistent and bio-accumulative toxic material that can unintentionally become part of the rubber matrix of the tire.

8 Tire testing performed by the California Energy Commission indicated a similar result (Fig. 4, A and B).

Rating and labeling. The European Union has also adopted a regulation (EC Labeling Regulation 1222/2009; European Parliament, 2009b) for mandatory labeling of new vehicle and replacement tires beginning in November 2012 to create market "pull" for efficiency beyond minimum standards. The mandatory program was spurred at least in part by the lack of success of the voluntary "Blue Angel" labeling program, as the Blue Angel website does not show any tire manufacturers participating in the tire labeling program (Blue Angel, 2011). A study sponsored by the Commission of the European Communities predicts that labeling programs will raise the efficiency of most tires above the minimum standards (Fig. 5). Tires for passenger vehicles, and for certain other tires designed for maximum loads of 1450 kg, will be rated on rolling resistance and wet grip according to an A-to-G scale (Table 3). The A-to-G grading system shown in Figure 6 is also used for passenger vehicles and consumer goods. Because relatively few tires qualify for the A rating at present, the system leaves room for tire improvement; this is in contrast to systems such as U.S. traction ratings, where almost all tires are rated A.

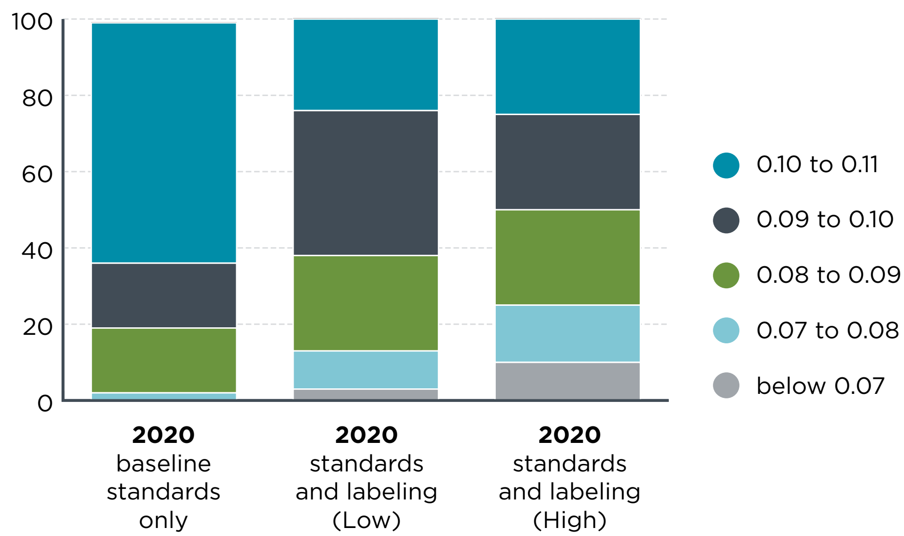


Figure 5. Predicted E.U. 2020 tire RRC with dual efficiency and safety labeling. Data from Commission of the European Communities (2008a).

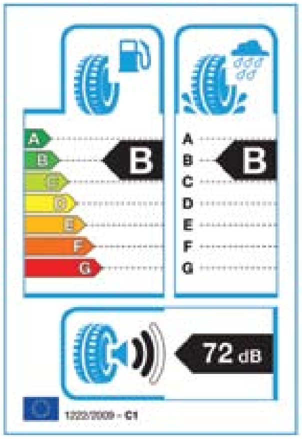


Figure 6. European Union tire label.

Tire manufacturers must provide consumers with information at the point of purchase, and they must also maintain websites offering rolling resistance and other technical information for both passenger and heavy-duty vehicles (EC Regulation 1222/2009, Article 5; European Parliament, 2009b). The E.U. labeling regulation also requires that the European Commission develop a fuel-savings calculator that could eventually be posted on each manufacturer's website.

The implementing regulation (EC Regulation 661/2009, Article 16; European Parliament, 2009a) requires that member states establish and report rules for penalties that are "effective, proportionate and dissuasive" and cover at a minimum false declarations, falsifying test results, and withholding data. Implementing regulations have been drafted that would allow member states to verify manufacturer declarations. National verification will be important to establish confidence in the accuracy of the ratings.

Table 3. Tire rating grades in Japan and the European Union.

ROLLING RESISTANCE COEFFICIENT (DIMENSIONLESS)	JAPANESE GRADE	E.U. GRADE	NOTES
RRC ≤ 0.0065	AAA	A	These grades qualify for the low-energy tire logo in Japan.
0.0066 < RRC < 0.0077	AA	B	
0.0078 < RRC < 0.0090	A	C	
0.0091 < RRC < 0.0105	B	E	Tires below this grade will be phased out in the European Union when E.U. phase 2 is implemented (the E.U. grading system does not contain a level D).
0.0106 < RRC < 0.0120	C	F	
RRC ≥ 0.0121	(do not qualify)	G	Tires in this grade will be phased out in the European Union when E.U. phase 1 is implemented.

JAPAN

Rating and labeling. In January 2010, Japanese manufacturers began to implement a voluntary passenger vehicle summer tire efficiency and safety labeling program (Tyre Express, 2010). Tires must have at least 0.012 dimensionless RRC (expressed as 12.0 N/kN) and meet minimum wet-grip requirements to qualify for the labeling program described in Table 3. Tires with at least 0.009 RRC (expressed as 9.0 N/kN) also qualify for the low-energy tire logo shown in Figure 7. Durability and winter tire requirements have not been included initially but may be reconsidered in the future.

The labeling program is based on testing under Japanese Industrial Standards (JIS) D4234:2009, which is consistent with ISO 28580, the test method adopted in the United States and the European Union. Japanese manufacturers export more than 35 million tires per year to North America and the European Union (Japan Automobile Tyre Manufacturers Association, 2009; Ministry of Land, Infrastructure, Transport and Tourism, 2009) and would thus benefit from harmonization with U.S. and E.U. test methods.

SMARTWAY TRUCK TIRES

The U.S. Environmental Protection Agency has designated heavy-duty truck tires with low rolling resistance from 11 different manufacturers as SmartWay tires under the voluntary SmartWay program. According to EPA, SmartWay tires can improve fuel economy by 3% or greater for line-haul trucks and thereby reduce nitrogen oxide emissions. Low-rolling-resistance tires can be used with lower-weight aluminum wheels to further improve fuel savings.

The California Air Resources Board has adopted a regulation that requires SmartWay tires for new heavy-duty vehicle tires, with such tires to be phased in for existing fleets.

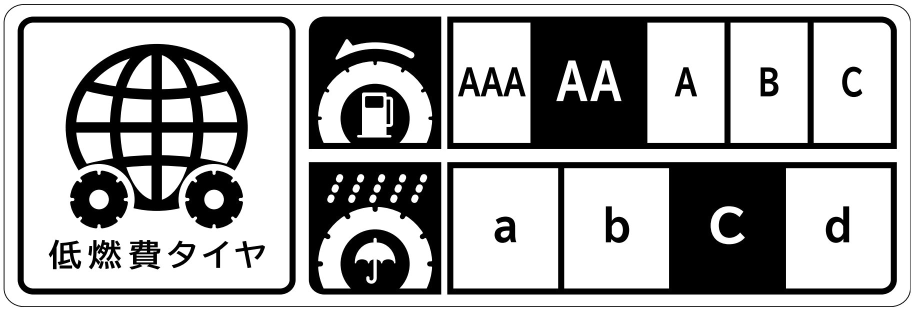


Figure 7. Sample Japanese tire label. Left, low-energy tire logo; upper right, RRC grade; lower right, wet-grip grade.

The Japanese tire labeling program does not prohibit sales of tires with poor efficiency. However, an RRC of 0.012 could become a minimum marketplace standard in practice. This could occur if consumers avoid unlabeled tires that are not labeled because their RRC is worse than 0.012, or if manufacturers phase out tires with RRC worse than 0.012 because of requirements in export markets such as the European Union. Countries that adopt a labeling program without standards, or in advance of standards, should also consider a minimum level to encourage manufacturers to achieve a certain floor level of efficiency.

SOUTH KOREA

Rating and labeling. South Korea will implement a domestic tire labeling program for efficiency and traction for replacement tires on a voluntary basis in 2011 and on a mandatory basis in 2012. The program would save at least 1 million metric tons of CO_2 per year if consumers respond by choosing low-rolling-resistance tires (Korea Energy Management Corporation [KEMCO], 2010). The program is also intended to maintain market share for South Korean exports to countries that have adopted or are adopting standards.[9] Labeling bins similar to those used by the European Union and Japan have been proposed (KEMCO, 2010), and South Korea is likely to adopt a test method consistent with ISO 28580.

Standards. Mandatory standards in South Korea are proposed for implementation in 2013. The standards are proposed at the equivalent of 0.012 RRC for passenger cars and wet grip of 110% (Campaign for Better Tyres, 2011), similar to the E.U. phase I minimum standards, and 0.0105 RRC for light-truck tires, similar to E.U. “C2” tires. Potential standards for heavy-duty tires similar to E.U. “C3” tires are under consideration (KEMCO, 2010).

9 The European Union accounts for 34% of South Korea’s tire exports, whereas the U.S. passenger vehicle and light-truck market consumed about 20% of South Korean total on-road passenger vehicle tire production as of 2009 (data from Rubber and Plastics News, 2010; U.S. International Trade Commission, 2009). Some of these data include aviation production, which is not expected to be significant relative to production for on-road vehicles.

UNITED STATES

Rating and labeling. Efforts to establish a labeling program in the United States have achieved progress in several areas but have not yet resulted in the labeling of any tires. The Energy Independence and Security Act of 2007 requires that the National Highway Traffic Safety Administration (NHTSA) finalize a national tire fuel efficiency consumer information program to educate consumers about automotive replacement tires' effects on fuel consumption, safety, and durability. Replacement tires make up about 80% of the 300 million tires sold annually in the United States (National Research Council, 2006, p. ES-4), with an estimated 24,000 types of tires available, excluding certain specialty tires (Lambillotte, 2009); as mentioned earlier, replacement tires tend to lag the efficiency of tires for new vehicles.

NHTSA finalized a rule on March 23, 2010 that adopts ISO 28580:2009(E) as the rolling resistance testing procedure (U.S. NHTSA, 2010, p. 13) but does not finalize a proposed rating, labeling, and consumer education program for efficiency, safety, and durability. Instead, NHTSA will conduct additional consumer research in 2011 and then publish a new proposal for how to best convey the rating information to consumers. The March 23, 2010 rule states that manufacturers will be required only to provide ratings to NHTSA, not their actual tire testing data. However, the future re-proposal may provide an opportunity to reconsider submission of testing data to NHTSA to facilitate verification.

The California Energy Commission (CEC) has also proposed a replacement tire efficiency program. Unlike the federal program, the California program would cover light-truck tires that are also used for large pickup trucks and SUVs. Light-truck tires represent about 12% of the market for all passenger vehicle tires (Tuvell, 2009). The proposed program would require testing data as the basis for each tire rating. CEC has not announced whether it will finalize the proposed state program or wait for a national program.

The program proposed by NHTSA as well as the program proposed by CEC in 2009 would rate tires on the basis of rolling resistance force (RRF)—the force needed to overcome rolling resistance with a given load per tire. Whereas RRC relies on the expectation that its value scales linearly to any load, RRF requires no such assumption. NHTSA has not yet decided whether to finalize RRF as the metric for rating efficiency.

Programs to Improve Tire Efficiency and Safety Through Proper Tire Inflation

OPTIONS FOR IMPROVED INFLATION

Proper tire maintenance, especially with respect to inflation, is another area for potential improvement. For a tire inflated to pressures between 24 and 36 psi, each drop of 1 psi leads to a 1.4% increase in its rolling resistance.

The response is even greater for pressure changes below 24 psi (National Research Council, 2006, p. 46). For various reasons, tires can lose 3 to 6% pressure per month; in the European Union, 50% of all cars are driven on underinflated tires (Commission of the European Communities, 2008b, p. 12). A NHTSA study that preceded the implementation of TPMSs found that 27% of passenger vehicles and 32% of light trucks and SUVs had at least one tire that was underinflated by 25% or more (Thiriez & Bondy, 2001, p. 11). Automatic monitoring and manual pressure checks are both important contributors to tire efficiency (and, as noted earlier, can help to improve tire wear and safety as well).

Both direct and indirect automatic TPMSs are in use. Direct TPMSs rely on pressure monitors located in tire valve stems. Indirect systems typically detect changes in wheel rotational speed by means of a sensor wrapped around the wheel (inside the tire) in combination with anti-lock brake system components. Indirect systems may be less accurate and more dependent on proper calibration than direct tire pressure sensors, but they may also be less expensive. In either case, a warning signal alerts the driver when severe underinflation is detected.

Despite the installation of TPMSs in new passenger vehicles sold in the United States since fall 2007 (with phase-in from model year 2006), manual tire pressure gauge checks will remain important. A vehicle's TPMS will not alert the driver unless underinflation has exceeded a certain threshold of tire pressure, as discussed below; in ordinary circumstances, drivers tend to visually estimate whether their tires are correctly inflated—a common but inaccurate method (Rubber Association of Canada, 2010, p. 29). Thus, a TPMS could lead to a false sense of security when tires are underinflated by less than this triggering threshold.[10]

The use of nitrogen to inflate tires is another option that has gained some traction, at least in the North American market (Consumer Reports, 2007). The available information indicates that nitrogen inflation has the potential for somewhat lower leakage rates, but nitrogen inflation does not yet have an extensive track record.[11]

Table 4 summarizes existing tire inflation programs in the United States and the European Union as well as programs under development in China, Japan, and South Korea.

10 A recent Canadian study illustrates the continuing need for additional use of pressure gauges to manually check tire pressure. This study of Canadian drivers found that 21.5% of drivers had at least one tire underinflated by 10 to 20%, which is well below the range that would be detected by TPMSs deployed in Canada as spillover from U.S. TPMS standards. An additional 10.5% of drivers had at least one tire underinflated by 20% or more (Rubber Association of Canada, 2009, p. 29).

11 A study of Canadian drivers found that 6% of drivers had nitrogen-inflated tires (Rubber Association of Canada, 2010, p. 49). Consumer Reports (2007) found moderate inflation benefits in 31 pairs of tires stored unloaded for a year. However, given limited data and experience with nitrogen inflation, this paper focuses on opportunities to keep tires inflated with air.

Table 4. Tire inflation programs.

COUNTRY/ REGION	TIRE INFLATION PROGRAM(S)
United States	Tire pressure monitoring system (TPMS) with underinflation detection threshold of 25% currently required for all new passenger vehicles California automotive service provider tire inflation regulation effective as of 2010
European Union	Mandatory TPMS standard with phase-in beginning in 2012; detection threshold initially set at 20% with second-stage threshold of 15% under consideration
China	Voluntary standard drafted with 25% underinflation detection threshold
South Korea	Mandatory standard proposed in 2010
Japan	Standards under consideration

TIRE INFLATION PROGRAMS

United States. The present NHTSA TPMS standards require a warning to the driver if tires are underinflated by 25% or more. Although the detection level has been effective at achieving safety improvements with some fuel economy co-benefits, it is not set at a level for optimal fuel economy benefits. The standard was phased in beginning in 2005, and at least 50 million of these systems are now on the road today, with additional spillover into the Canadian market.[12] NHTSA estimates that the rule will prevent more than 100 fatal accidents and more than 8,000 non-fatal accidents per year (U.S. NHTSA, 2005, p. ES-ii).

California adopted a requirement in 2010 that automotive service companies check their customers' tires and inflate them if needed. Emission reductions of more than 700,000 metric tons of CO_2 annually were initially expected (CARB, 2009b), with the amount declining but not disappearing as TPMS systems become more common.[13] In addition, California (Assembly Bill 531 passed in 1999) requires that gas stations provide free compressed air to customers. NHTSA also intends to develop a consumer tire inflation education program, as required in the Energy Independence and Security Act of 2007. A 2009 Canadian survey reported that the most effective form of public education is a notice at the gas pump, followed by

12 The ICCT estimates that there are at least 50 million TPMSs on the road, based on the NHTSA phase-in schedule and vehicle sales data from AutoNews.

13 Revisions to allow driver opt-outs create some uncertainty about how much of the expected benefit of the program will be realized in practice (CARB, 2009c, section D.5).

advertisements and public service announcements (Rubber Association of Canada, 2010, p. 48).

European Union. E.U. Regulation 661/2009, Article 9, requires installation of TPMSs to improve fuel efficiency and safety in passenger vehicles designed for nine or fewer people. The regulation will be phased in for new model approvals of vehicles and components beginning November 1, 2012, and for all new vehicles and components beginning November 1, 2014 (Articles 13.2 and 13.5). A report by the Netherlands Organization for Applied Scientific Research recommended detection levels at 15 to 20% underinflation to achieve better fuel savings relative to the older and less strict U.S. TPMS standards (Smokers et al., 2006). Detection thresholds are set at 20% (Society of Automotive Engineers, 2011) initially, with the European Commission considering a second phase with a lower detection threshold of 15% (European Parliament, 2010). As noted earlier, the stricter E.U. TPMS standards are expected to achieve significantly better fuel consumption improvements and greenhouse gas emission reductions than the older U.S. TPMS standards at a reasonable cost.

Asia. China has drafted voluntary standards that would require TPMSs installed in light-duty and commercial vehicles to provide a rapid response when tires are more than 25% below correct inflation, to display the actual pressure and an indication of which tire is underinflated, and to operate when the vehicle is stationary (China Automotive Technology and Research Center, 2009). South Korea has proposed a mandatory TPMS standard for new vehicles but has not yet finalized the standard (Rho, 2011). TPMS requirements are also under consideration in Japan.

Best Practice Recommendations

Several countries and regions have implemented one or more programs to improve tire efficiency, but no country or region has a complete program in place to address all aspects of tire efficiency. Although additional experience will, of course, provide a basis for more complete and thorough analysis, experience to date supports the following best practice recommendations:

- **Tire efficiency rating and labeling.** Rating and labeling programs are an important first step in improving tire efficiency because they encourage customers to choose, and retailers and manufacturers to provide, more efficient tires. About 60 to 65% of global passenger vehicle tire production will be tested for rolling resistance for programs in the European Union, the United States, or Japan, and such a large information base would facilitate the rapid adoption of rating and labeling programs in other countries and regions as well.

  Simple bins (such as 1 through 5, or A through G) with meaningful differentiation between "bins," including room for future years after expected improvements take place, will be the most effective way to present efficiency data to consumers. A minimum efficiency level needed to qualify for a label (such as 0.012 rolling resistance coefficient) and a symbol for top-rated products can also help to reinforce the use of these labels. Online information and fuel-savings calculators are a valuable complement to labels provided at the point of purchase.

- **Tire efficiency standards.** Just as programs to improve the efficiency of replacement tires can benefit from a "pull" from labeling and consumer education to encourage top performance, minimum standards can create a "push" to bring up the bottom end of the market. This is a common model for many types of consumer products, as information programs alone may not reach all consumers and/or may not completely overcome market barriers to more efficient products. Countries that choose to begin with labeling programs alone should evaluate their effectiveness over time and determine whether complementary standards are also necessary.

  Tire efficiency standards may require more lead time than labeling programs for the transition to more efficient designs in cases where manufacturing shifts would be required to meet minimum standards. Given that E.U. standards will already require transition in the market, however, the lead-time issue may not be as large for other countries that adopt standards in the near term with harmonized phase-in deadlines.

- **Tire efficiency testing and verification.** Verifiable testing data that are available to government regulators will enhance the accuracy and credibility of tire ratings and compliance with standards.
- **Importance of proper inflation.** Proper tire inflation is another important tactic for achieving safety, environmental, and economic benefits. Standards requiring the installation of TPMSs as a safety and efficiency measure are an effective strategy, aided by the global spread of the technology. A TPMS detection threshold of 15 to 20% is feasible, providing larger efficiency benefits than the 25% threshold mandated by the U.S. 2005 TPMS standards.

  Consumer education programs and automotive service "check and inflate" programs are complementary options that can be designed to fit local circumstances and will continue to provide benefits even in areas where TPMSs are phased in.

- **Comprehensive regulation.** Comprehensive programs that address efficiency together with other important attributes, including safety, durability, and noise, will help to achieve greater synergies and reduce any possible trade-offs or unintended consequences.

  Although there is no indication that low rolling resistance and safety goals conflict, labeling for safety attributes and, if necessary, minimum safety standards will prevent backsliding. Proper inflation practices will improve both efficiency and safety.

Programs to encourage low rolling resistance should also provide consumers with information that encourages improvements in treadwear so as to reduce tire disposal rates. Proper tire inflation will improve durability along with efficiency and thus reduce the environmental impact of tire disposal, and potentially also reduce fine particulate emission rates. Moreover, the process of redesigning tires to decrease rolling resistance may offer design opportunities to reduce tire noise.

Adoption of best practices globally could lead to a reduction in annual greenhouse gas emissions by more than 100 million metric tons annually. Together, these policies to improve the energy efficiency of tires can yield substantial cost savings, energy security benefits, and air pollution reductions.

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