A look at rolling resistance, fuel economy

By Walter H. Waddell
Tire Technology Training Co. Inc.

Executive summary

The rolling resistance coefficient (RRC) data for about 100 models of passenger car radial tires had been determined by following the ISO 28580 test protocol.

Average RRC values are calculated for the three global regions where tires were manufactured and purchased: Americas, Europe and Asia-Pacific. Tire RRC values are assigned into energy efficiency classes based on the regulations of the Commission for the European Union.

Using available 2014 data on the number of light vehicles worldwide, the average distance vehicles are driven each year, and the average fuel economy per vehicle, the potential fuel savings are calculated if tire RRC is reduced changing it into a more energy efficient class.

Corresponding potential savings in CO_2 emissions are estimated. Similar data for light vehicle use in the U.S. allows for calculation on potential gasoline savings and estimation of CO_2 emission reductions.

As a result of the Common Position (EC) No. 18/2009 adopted by the European parliament and the Counsel for the European Union on Nov. 20, 2009, the labeling of tires with respect to fuel efficiency and other essential parameters became mandatory on Nov. 1 2012.[1] See **Fig. 1**.

TECHNICAL NOTEBOOK
Edited by Harold Herzlich

The Working Party on Noise, WP.29, developed a one-condition test method adopted as ISO 28580 for passenger car (C1), light truck (C2), and truck and bus (C3) tires in order to determine the energy efficiency class using the rolling resistance coefficient (RRC in kg/t). Japan[2-3] and South Korea[4-5] already have established mandatory tire labeling, and Brazil[6-7] and China[8-9] are planning to adopt regulations similar to that of the EU.

In the U.S., the National Highway Traffic Safety Administration have studied tire rolling resistance[10-11] and fuel efficiency rankings, proposing new standards,[12-13] but have not yet adopted mandatory tire labels. An analysis was made of available data on about 100 passenger car tire RRC values in order to calculate the potential fuel savings, and to estimate the corresponding CO_2 emission reductions, upon reducing tire RRC values to convert it into a more energy efficient class.

Experimental

Rolling resistance coefficient values on roughly 100 passenger car tires[14—15] that were manufactured worldwide by 25 tire companies were analyzed using SAS JMP statistical discovery software.

Rolling resistance force values were measured by Smithers Rapra (Ravenna, Ohio) against a 1.707-meter drum of a model 1095 laboratory roadwheel that was covered with friction material to simulate a pavement microtexture.

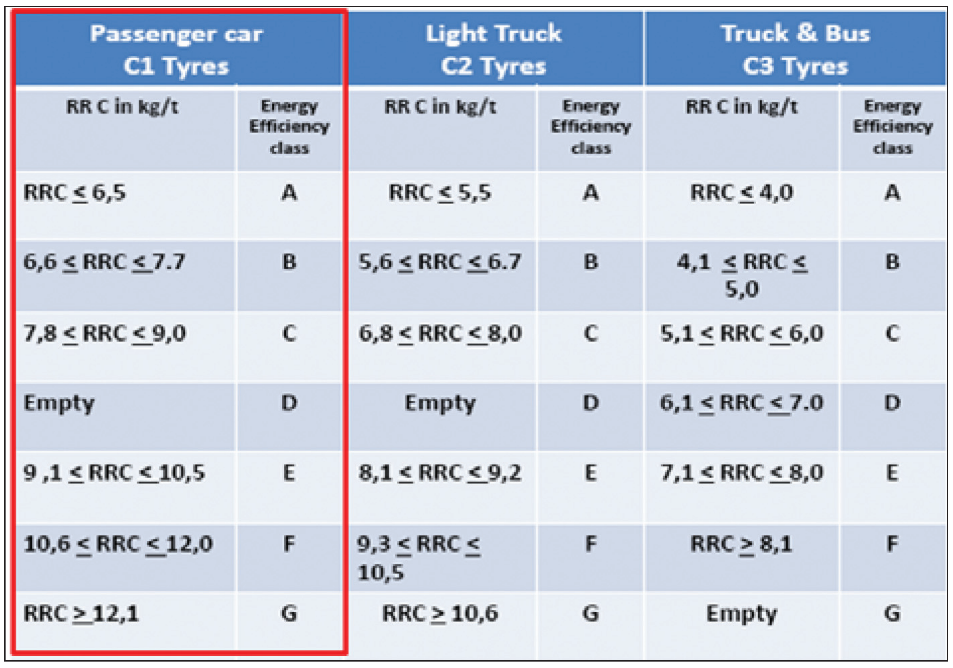
ISO 28580 protocol (80 kmph, 80 percent of maximum tire load (TR&A; ETRTO), 210 kPa inflation pressure) were used to generate rolling resistance coefficients by dividing by measured force by the applied test load and correcting to a 2.0-meter drum. RRC values are reported as kg/t.

Results and discussion

The average RRC value for ~100 passenger car tires manufactured and purchased worldwide is 9.9 kg/t. Tires are assigned into an energy efficiency class using the EU protocol shown in **Table I**[1]. Also, EU regulation No. 661/2009 has set timetables for the mandatory elimination of C1 and C2 tires with RRC values >12.0 kg/t (1 November 2014) and RRC values >10.5 kg/t (1 November 2018),

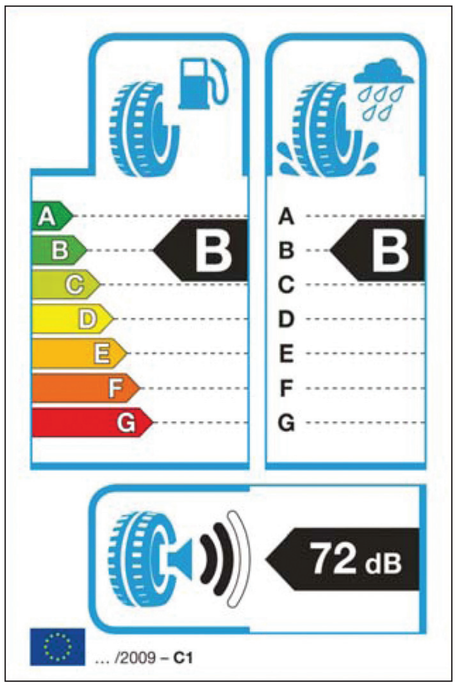
See **Rolling,** *page 32*

Table I. Energy efficiency classes of RRC.[1]



Passenger car C1 Tyres		Light Truck C2 Tyres		Truck & Bus C3 Tyres	
RR C in kg/t	Energy Efficiency class	RR C in kg/t	Energy Efficiency class	RR C in kg/t	Energy Efficiency class
RRC ≤ 6,5	A	RRC ≤ 5,5	A	RRC ≤ 4,0	A
6,6 ≤ RRC ≤ 7.7	B	5,6 ≤ RRC ≤ 6.7	B	4,1 ≤ RRC ≤ 5,0	B
7,8 ≤ RRC ≤ 9,0	C	6,8 ≤ RRC ≤ 8,0	C	5,1 ≤ RRC ≤ 6,0	C
Empty	D	Empty	D	6,1 ≤ RRC ≤ 7.0	D
9 ,1 ≤ RRC ≤ 10,5	E	8,1 ≤ RRC ≤ 9,2	E	7,1 ≤ RRC ≤ 8,0	E
10,6 ≤ RRC ≤ 12,0	F	9,3 ≤ RRC ≤ 10,5	F	RRC ≥ 8,1	F
RRC ≥ 12,1	G	RRC ≥ 10,6	G	Empty	G

Fig. 1. Example European tire label.[1]



The author

Waddell

Walter H. Waddell has more than 40 years of research and development experience using state-of-the-science equipment to solve applied technical problems and to answer questions on materials for the tire and rubber industries.

He holds a bachelor's degree in chemistry from the University of Illinois at Chicago, a doctorate from the University of Houston and a research associate in chemistry from Columbia University

Waddell has been an associate professor of chemistry at Carnegie-Mellon University; section head in research at Goodyear; senior scientist in silica technology at PPG Industries; and senior research associate in polymers technology at ExxonMobil Chemical Co.

Waddell has been granted 37 patents and five trade secrets and has written 150 publications in technical journals and books. He has presented 150 papers at meetings and universities and to government organizations.

Among his awards are a National Institutes of Health Research Fellowship; the Sparks-Thomas Award and the Melvin Mooney Distinguished Technology Award from the ACS Rubber Division; Distinguished Corporate Inventor from PPG Industries; a Distinguished Service Award and Outstanding Service Award from the Rubber Division.

Waddell is a member of the ACS Rubber Division (was chair in 2011), ASTM F09 and SAE International.

Rolling

Continued from page 32

corresponding to energy efficiency class G and class F tires, respectively.[16]

RRC data were analyzed based on three regions that the tires were manufactured and purchased: Americas, Europe and Asia-Pacific. Results show that for tires manufactured in the Americas and in European countries, RRC values are similar with an average of 9.7 kg/t. However, for tires manufactured in Asia-Pacific countries, a higher average RRC value of 10.1 kg/t is obtained. See **Fig. 2**.

Further analysis of the Asia-Pacific region shows that for 29 tires manufactured by 15 tire companies in China, a statistically significant +0.75 kg/t higher average RRC value of 10.46 kg/t is obtained. Tires manufactured in the other two worldwide regions or in the remaining Asia Pacific countries except China have a RRC ~9.7 kg/t (**Fig. 3**). Tires were assigned into the six EU energy efficiency classes; note that class D is vacant for both C1 passenger car and C2 light truck tires (**Fig. 4**).

An analysis was made of the potential fuel savings and resulting CO_2 emissions savings worldwide by (1) eliminating the five tires that are in the EU energy efficiency class G by reducing RRC values to become class F tires (**Fig. 5**); (2) eliminating the now 40 class F tires by reducing RRC values to become class E tires (**Fig. 6**); (3) eliminating the now 74 class E tires by reducing RRC values to become class C tires (**Fig. 7**); and (4) using the relationship that for 10 percent better tire rolling resistance, fuel consumption reduction for a car is approximately 1.6 percent.[17]

In 2014, there were approximately 907 million passenger cars and 329 million commercial vehicles in use worldwide.[18] See **Fig. 8**.

The average distance driven in 2014 was 14,188 kilometers per passenger car, thus totaling 12.87 billion kilometers driven annually by all passenger cars worldwide. The average fuel economy per passenger car was 9.1 L/100-km, meaning that an average of 1,291 liters of fuel was used by each passenger car worldwide.

Thus, a total of 1,171 billion liters of fuel was calculated as being consumed by all passenger cars worldwide.

If all countries worldwide were to convert all of the energy efficiency class G tires (~5 percent of tires) into class F tires by manufacturing tires with RRC values <12.0 kg/t, on average passenger cars equipped with these tires potentially could save about 28 liters of fuel per year, using the relationship that 10 percent better rolling resistance reduces fuel consumption for a car about 1.6 percent.[17]

By reducing the RRC value of class F tires (combined class G and F tires were ~40 percent of all tires worldwide) into class E tires (RRC values <10.5 kg/t), then light vehicles equipped with these tires could potentially save about 25 liters per year. By further reducing the RRC value of all class E tires by reducing the rolling resistance to convert into class C (RRC <9.0 kg/t), then those vehicles could potentially save another 28 liters of fuel per year.

By combining the class G, class F and class E tires, about 75 percent of all tires worldwide would be affected. Potential savings worldwide are calculated to be 1.46, 12.1 and 34 billion liters of fuel each year respectively (**Fig. 9**).

Fig. 2. RRC values by region manufactured.

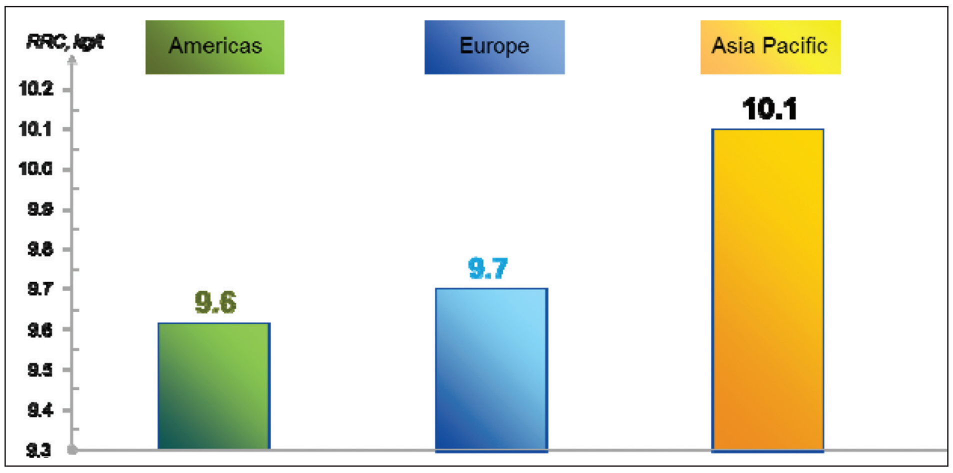


Fig. 3. RRC values by region manufactured and for manufactured in China.

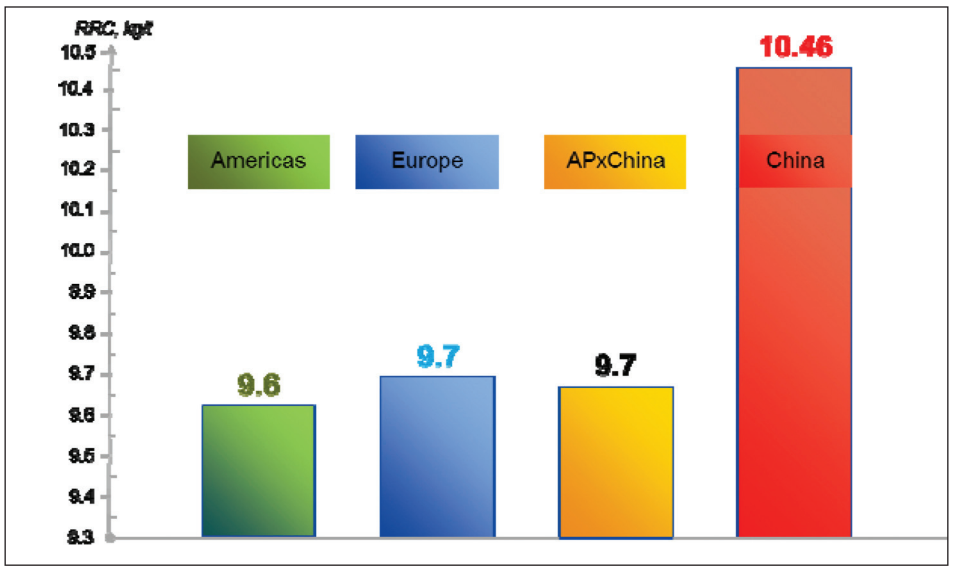


Fig. 4. Distribution of tires into six EU energy efficiency classes (class D is vacant).

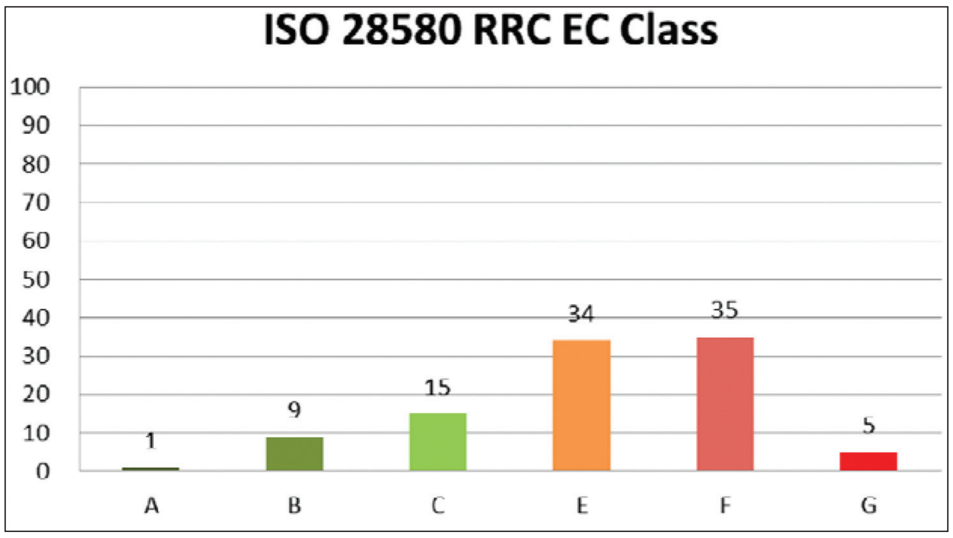
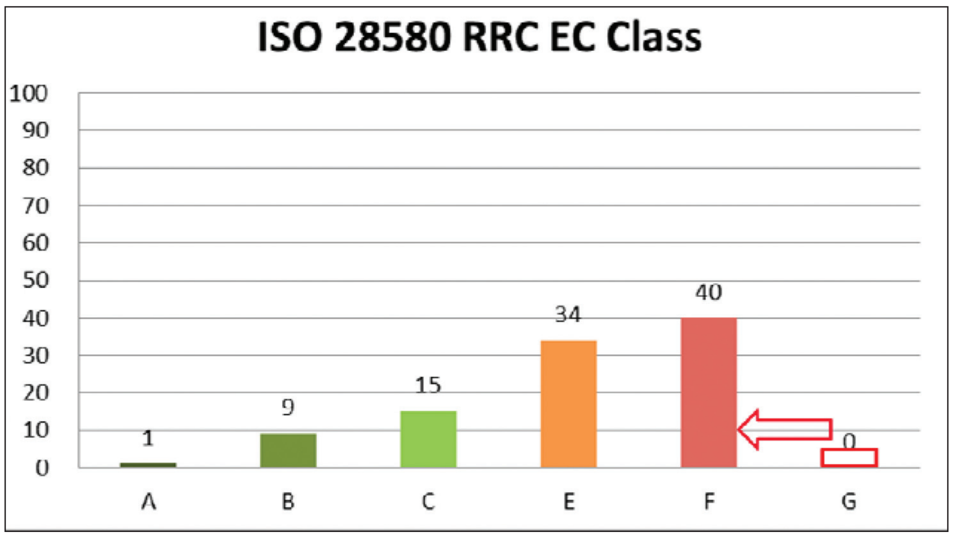


Fig. 5. Distribution into EU energy efficiency classes eliminating class G tires.



Plants

Continued from page 30

Company/ Plant location	Year opened	DOT codes	Employees	Tire types	Estimated capacity
Israel					
Alliance Tire Co. (1992) Ltd. (Yokohama Rubber Co. Ltd.)					
Hadera	1952	CD,1CD	750	4,6,7 (r,b)	42,000 t/y
Kazakhstan					
Kazakhstan government					
Chimkent	1981	—	6,147	1,3,4	4.5 mil. u/y
Turkey					
Anlas Anadolu Lastik Sanayi Ve Ticaret A.S.					
Bolu/Duzce	1974	KL,RJ,67	300	4,5,7 (r,b)	5,000 u/d
Billas ve Kauçuk San. Tic. A.S.					
Bilecik	2011	—	—	4,5,7 (b)	3 mil. u/y
Brisa Bridgestone Sabanci Lastik Sanayi ve Ticaret A.S. (Bridgestone Corp. and Sabanci Group joint venture)					
Izmit	1974	L5,1L5	1,504	1,2,3,4,6 (r,b)	30,273 u/d
Goodyear Lastikleri Turk A.S. (Goodyear)					
Adapazari	1960	C0,C01	700	1,2,3,4,6 (r,b)	17,000 u/d
Izmit	1963	PA,1PA	700	2,3,4 (r,b)	3,000 u/d
ÖZKA Lastik ve Kauçuk Sanayi Ticaret A.S.					
Kocaeli, Kukllar	2005	—	—	2,4,7 (r,b)	—
Petlas Tyre Industry & Trade Co. (Abdulkadir Ozcan Corp.)					
Kirsehir	1976	8S,18S	2,300	1,2,3,4,6, 7,8 (r,b)	8.9 mil. u/y
Sumitomo Rubber AKO Lastik Sanayi ve Ticaret A.S. (Sumitomo Rubber Industries Ltd. and Abdulkadir Ozcan Lasktik Sanayi Ticaret A.S. joint venture)					
Cankiri	2015	AH,1AH	818	1 (r)	5,400 t/y
Turk Pirelli Lastikleri A.S. (Pirelli & C. S.p.A)					
Izmit	1962	XJ,1XJ	1,800	1,2,3,9 (r)	8 mil. u/y

Explanation of abbreviations

TIRE TYPES: 1—Auto; **2**—Light truck; **3**—Truck/bus; **4**—Agricultural; **5**—Motorcycle; **6**—Earthmover/OTR; **7**—Industrial; **8**—Aircraft; **9**—Racing
TIRE CONSTRUCTION: r—Radial; **b**—Bias-ply
PLANT CAPACITIES: u/d—Units per day; **u/y**—Units per year; **t/y**—Tons per year; **t/d**—Tons per day
Names in parentheses indicate the parent company.

This is estimated to correspond to 3.4, 27.8 and 78.5 million metric tons of CO_2 emissions that potentially would not be generated.[19] See **Fig. 10**.

Fig. 11 shows the percentage of tires affected. Finally, by converting these tires into EU energy efficiency class B tires (RRC <7.7 kg/t), even further increases in both the potential fuel and CO_2 savings could be expected.

In 2014, the U.S. had approximately 212 million registered drivers using a total of 240.2 million light vehicles[20] (**Fig. 12**). An average of about 12,600 miles was driven annually per light vehicle, thus around three trillion miles was driven in 2014. See **Fig. 13**.

With an average fuel economy of approximately 21.4 miles per gallon, the average light vehicle consumed an average of approximately 590 gallons of gasoline, and the U.S. consumed more than 141 billion gallons of gasoline (**Fig. 14**). These average values have not significantly changed in the last eight to 10 years. See **Figs. 12-14**.

Calculating similar results for the U.S. is slightly more complicated since tires are both manufactured in the U.S. and imported into the U.S., mainly from Asia-Pacific countries but also from European countries. For tires manufactured in the U.S., the average RRC=9.66 kg/t versus RRC = 0.25 kg/t for tires imported into the U.S.

The U.S. Department of Transportation, National Highway Traffic Safety Administration has studied tire rolling resistance[10-11] and proposed a tire label,[12-13] but has not yet adopted any mandatory tire fuel efficiency rating system. Thus, tires purchased in the U.S. were distributed into the EU energy efficient classes that were employed for the worldwide analysis of potential fuel and CO_2 savings. See **Fig. 15**.

No tires in this study that were purchased in the U.S. had RRC values >12.0 kg/t. Using the relationship that for 10 percent better rolling resistance, fuel consumption for a car is reduced about 1.6 percent[17] then by reducing the RRC value of EU energy efficiency class F tires (~43 percent of all tires in the U.S.) to EU class E tires (RRC <10.5 kg/t), then each light vehicle equipped with the EU class F tires could have potentially saved roughly 15 gallons of gasoline in 2014.

By further reducing the RRC values of EU class E tires (the combined EU class F and E tires are ~76 percent of tires studied that were purchased in the U.S.) to EU class C (RRC < 9.0 kg/t), then each light vehicle could have potentially saved another 12 gallons of gasoline in 2014.

Total potential light vehicle fleet savings in the U.S. is calculated to be 1.6 and 3.9 billion gallons of gasoline, respectively (**Fig. 16**). This is estimated to correspond to 13.7 and 34.4 million metric tons of CO_2 emissions potentially not being generated.[19.] See **Fig. 17**.

Since the total number of light vehicles in the U.S. has increased slowly, and the total miles driven per light vehicle has not significantly changed during the last 10 years, the amount of fuel consumed annually by all light vehicles is expected to be primarily reduced by increasing vehicle fuel economy. In the U.S. in 2014, the average age of passenger cars and light trucks was 11.4 years,[21] thus any improvements in total fuel consumed is expected to change at a slow rate.

As a secondary factor, improving tire RRC will help to contribute to overall vehicle fuel economy.

As tertiary considerations, maintaining tire inflation pressure, by (a) manufacturing tires with higher quality innerliners;[22-25] (b) using nitrogen gas inflation;[26-3] and/or (c) individuals continually re-inflating their tires, also could potentially contribute to overall light vehicle fuel savings and help to prevent CO_2 emissions from being generated.

Summary

If the RRC of EU energy efficiency class G tires were to be improved, worldwide fuel savings in 2014 potentially could have been 1.46 billion liters of fuel and 3.4 million metric tons of CO_2 not being generated. By reducing the RRC of EU energy efficiency class F tires to become class E tires, and further reducing the RRC values from

See **Rolling,** *page 34*

Fig. 6. Distribution into EU energy efficiency classes eliminating class F tires.

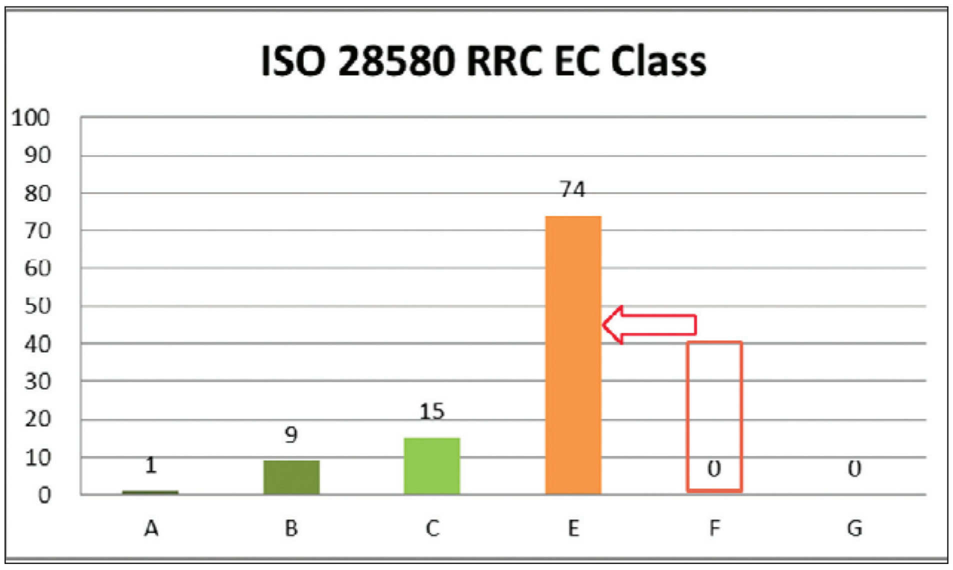


Fig. 7. Distribution into EU energy efficiency classes eliminating class E tires.

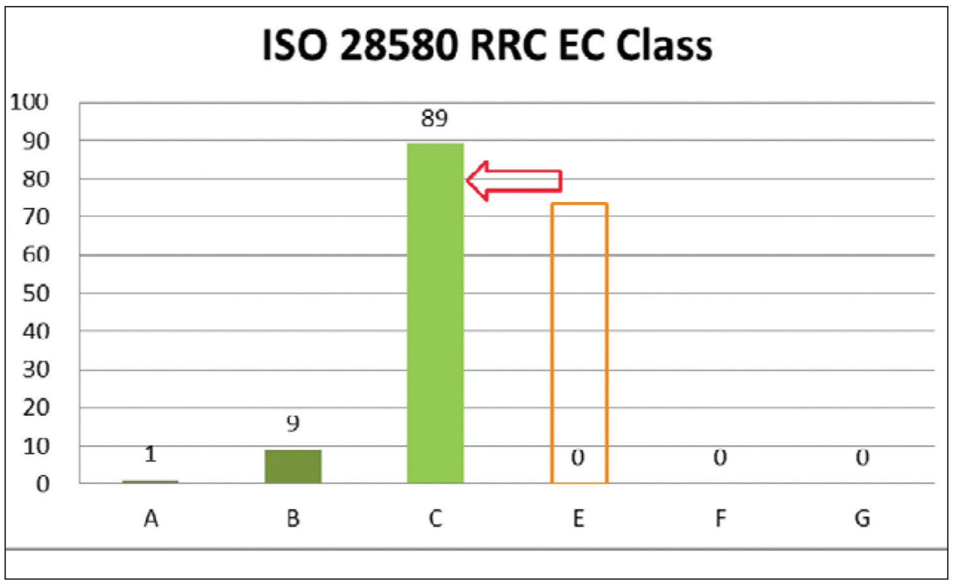


Fig. 12. Total registered light vehicles in the U.S.[20]

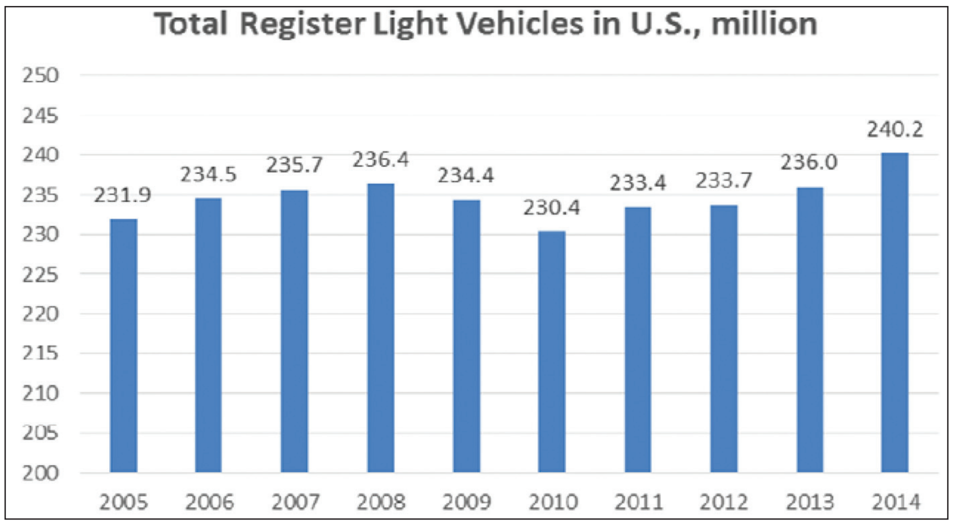


Fig. 8. Total worldwide passenger car and commercial vehicles.[18]

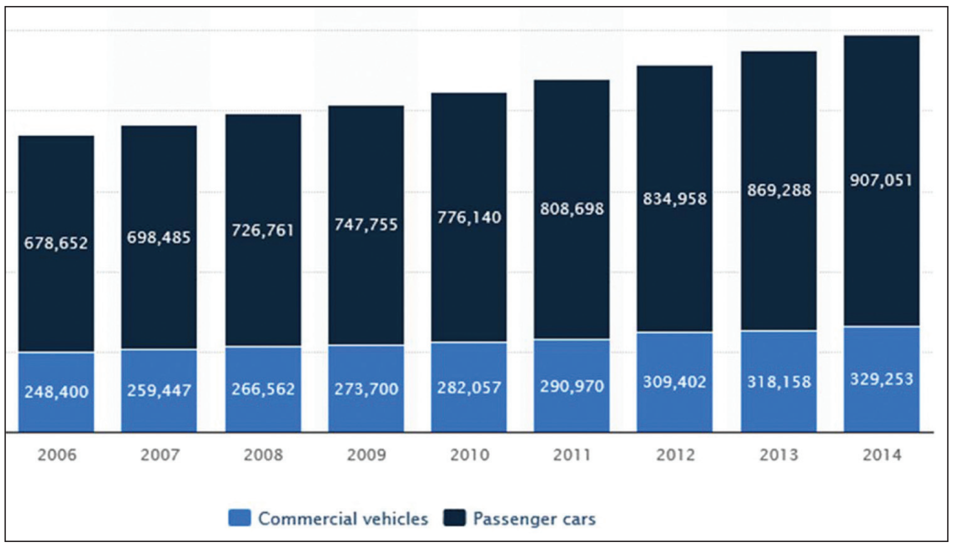


Fig. 9. Calculated potential fuel savings worldwide by improving tire RRC.

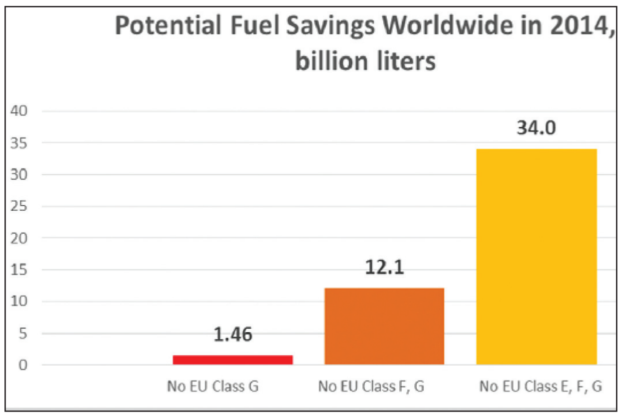


Fig. 10. Estimated potential CO2 emission reductions worldwide by improving tire RRC.

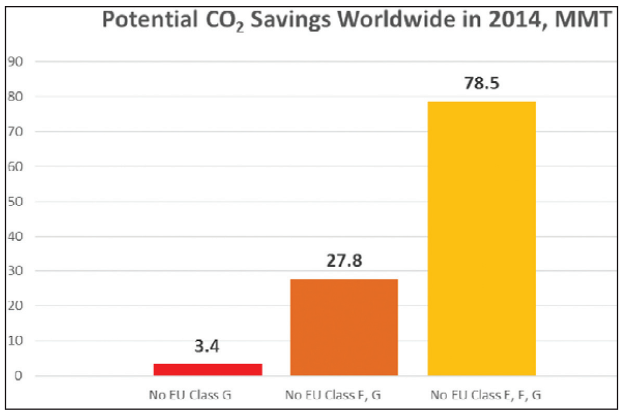
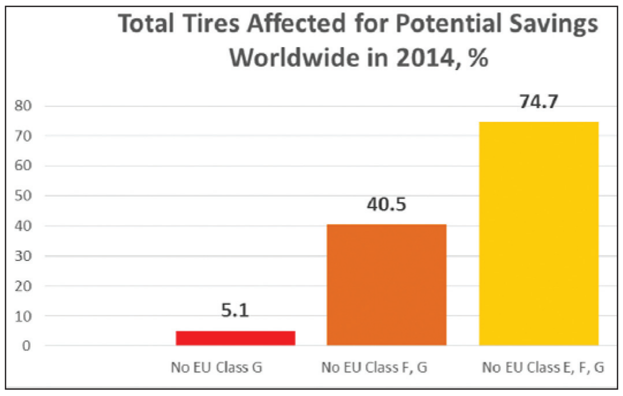


Fig. 11. Calculated percentage of tires affected by eliminating EU energy efficiency class G, F, and E tires by improving tire RRC.



Rolling

Continued from page 33

EU energy efficiency class E tires to become class C tires, potentially could have saved 12.1 and 34 billion liters of fuel, which corresponds to an estimated 27.8 and 78.5 million metric tons of CO_2 emissions not being generated, respectively; however, around 40 percent and 75 percent of tires worldwide would be affected.

For the U.S., gasoline savings in 2014 could potentially have been 1.6 billion gallons of gasoline and CO_2 emissions savings of 13.7 million metric tons by reducing the RRC values of EU energy efficiency class F tires to become class E tires.

Further reductions in RRC from EU energy efficiency class E tires to become class C tires, could have afforded potential savings of 3.4 billion gallons of gasoline, corresponding to 34.4 million metric tons of CO_2 emissions potentially not being generated, respectively; however, approximately 43 percent and 76 percent of all light vehicle tires in the U.S. would be affected, regardless of whether manufactured in the U.S. or imported into the U.S.

References

1. Official Journal of the European Union, C 298 E, Vol. 52, Dec. 8, 2009.
2. "Guideline for tyre labeling to promote the use of fuel efficient tyres (labeling system)," Dec. 4, 2009.
3. www.jatma.or.jp/english/labeling/pdf/labelingsystemE.pdf
4. Socio-Economic Effects as a Result of the Enactment of Tire Efficiency Rating (Labeling) System in South Korea Final Report, 2011.10.23.
5. http://lanxess.kr/uploads/tx_lxsmatrix/Tire_Efficiency_Rating_System_Abstract__v._English_.pdf
6. Ministerio do desenvolvimento, inudstria e comercio exterior intituto national de metrologia, qualidade e tecnologio-inmetro, Portaria n.º 544, de 25 de outubro de 2012.
7. European Rubber Journal, Aug. 14, 2012.
8. http://news.cria.org.cn/2/19429.html
9. http://news.cria.org.cnhttps://www.linkedin.com/pulse/china-introduces-tire-labelling-where-opportunities-david-shaw/2/19429.html
10. NHTSA Tire Fuel Efficiency Consumer Information Program Development: Phase 1, Evaluation of Laboratory Test Protocols, DOT HS 811 119, May 2009.
11. NHTSA Tire Fuel Efficiency Consumer Information Program Development: Phase 2, Effects of Tire Rolling Resistance Levels on Traction, Treadwear, and Vehicle Fuel Economy, DOT HS 811 154, August 2009.
12. NHTSA Notice of Proposed Rulemaking (NPRM), 49 CFR Part 575 "Tire Fuel Efficient Consumer Information Program," June 22, 2009.
13. NHTSA "Tire Fuel Efficient Consumer Information Program, Qualitative Survey Report, Dec. 15, 2011.
14. W.H. Waddell, "Effect of Inflation Pressure on Tire Rolling Resistance and Vehicle Fuel Economy," IRC 2014, Beijing, China.
15. J. Harris, L. Evans, J. MacIssac, and E. Terrill, "Tire Rolling Resistance for Light Vehicles I: Selection of Tires and Tests for Rating System Development," ITEC 2008, Akron, paper 18C-2.
16. Official Journal of the European Union, L 200/1, 31 July 2009.
17. Saeger (Continental), 4th Intelligent Tire Technology, Wiesbaden, 2008-10-21
18. www.statista.com/statistics/281134/number-of-vehicles-in-use-worldwide/
19. International Carbon Bank & Exchange, www.icbe.com/carbondatabase/volumeconverter.asp
20. U.S. Department of Transportation, www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_11.html.
21. U.S. Department of Transportation, www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_26.html_mfd
22. W.H. Waddell and R.C. Napier, *Rubber & Plastics News*, 14-18, 20-21, July 12, 2010.
23. W.H. Waddell, L. W.-J. Liu, and C. K.-S. Wee, *China Rubber*, **27**, 7 - 14, September/ October (2011).
24. W.H. Waddell, *Kautschuk Gummi Kunststoffe*, 65, 45-51 (2012).
25. R.C. Napier, W.H. Waddell, and D.F. Rouckhout, *Rubber & Plastics News*, 16-19, July 1, 2013; *Rubber & Plastics News* 16-18, July 15, 2013.
26. J. M. Baldwin, D. R. Bauer, and K. R. Ellwood, "Effects of Nitrogen Inflation on Tire Aging and Performance." ACS Rubber Division, Grand Rapids, Mich. May 2004.
27. J.M. Baldwin, D.R. Bauer, and K.R. Ellwood, *Rubber & Plastics News*, **33**, p 14,16,18-19, Sept. 20, 2004.
28. H. Herzlich, "The Science of Nitrogen Tire Inflation." December 2006; www.greenridesolutions.com/library.
29. J.D. MacIsaac, L.R. Evans, J.R. Harris, and E. Terrill, "The Effects of Inflation Gas on Tire Laboratory Performance," ITEC 2008.
30. W.H. Waddell, R.C. Napier, and D.S. Tracey, *Rubber Chemistry and Technology,* 82, 229-243 (2009).
31. R.C. Napier and W.H. Waddell, *Rubber & Plastics News*, 16-19, Nov. 30, 2009.

Fig. 13. Total miles driven by all light vehicles in the U.S.[20]

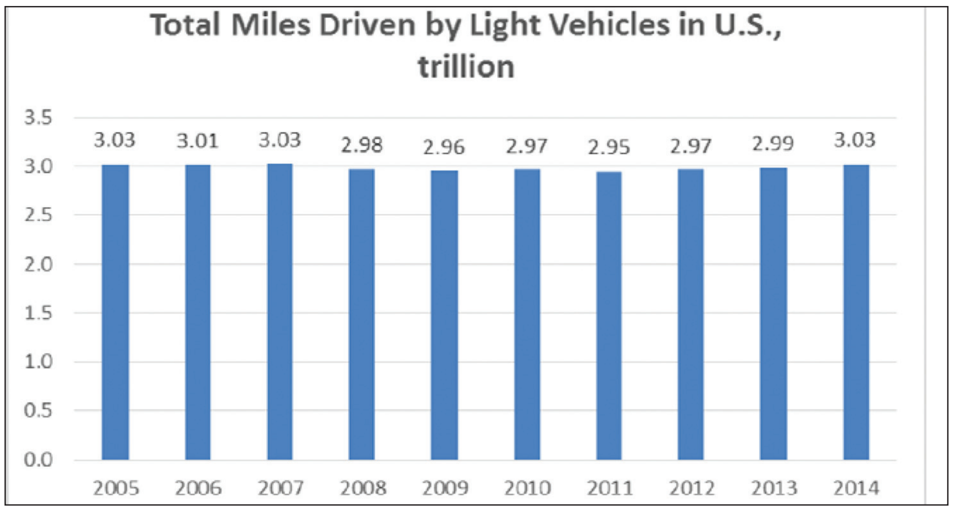


Fig. 14. Total gasoline consumed by all light vehicles in the U.S.

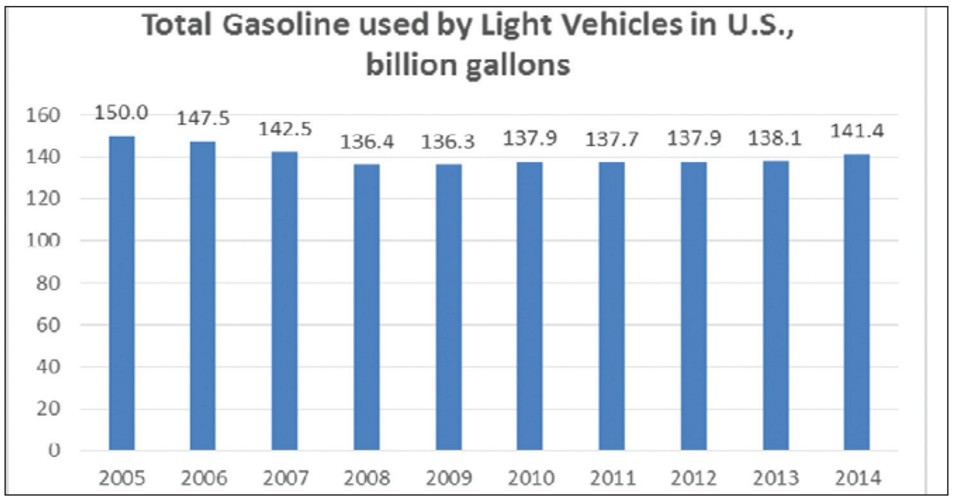


Fig. 15. Distribution of tires purchased in the U.S. by (a) manufactured in the U.S. versus (b) imported into the U.S.

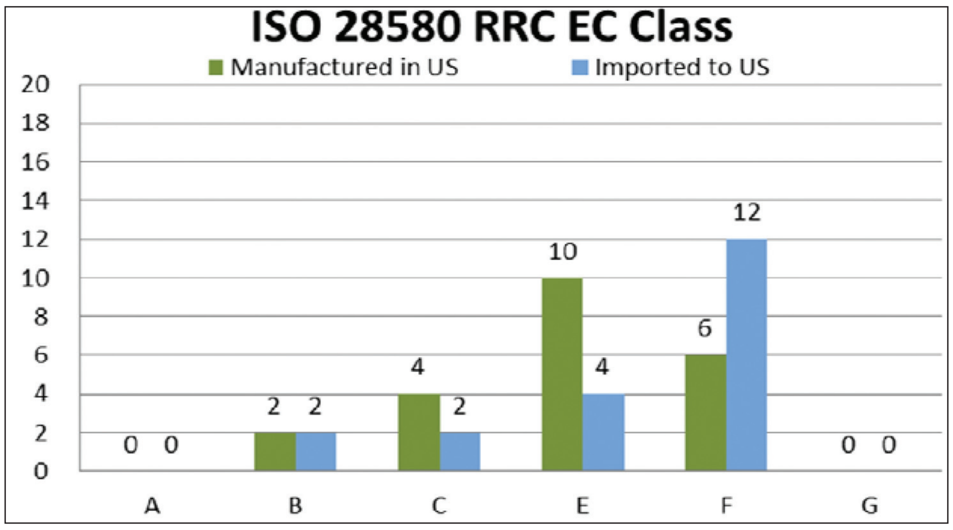


Fig. 16. Calculated potential fuel savings in the U.S. by improving tire RRC.

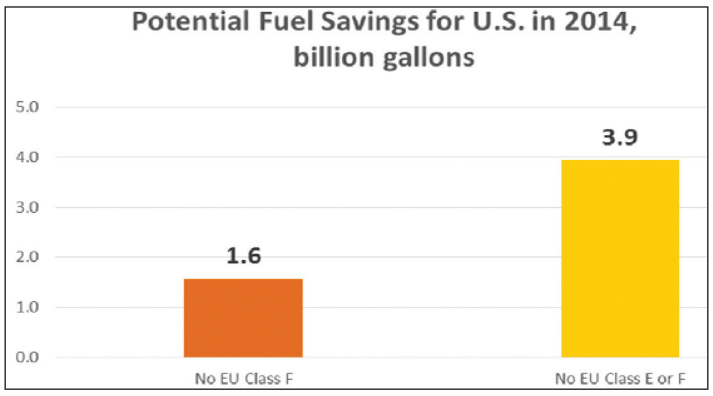
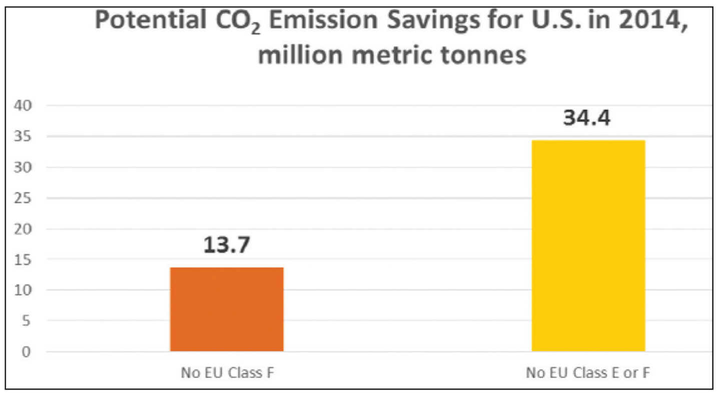


Fig. 17. Estimated potential CO_2 emission reductions worldwide by improving tire RRC.



Michelin relaunches Mexican plant

By Stephen Downer
Tire Business

LEON, Mexico—Michelin has started construction in Mexico of its 21st factory in North America—eight years after the global economic crisis of 2008 forced it to postpone the project.

"I'm really excited because a few years ago, in 2008, I had to come to this country to postpone our investment because of the crisis," Michelin CEO Jean-Dominique Senard said. "At the same time, I was incredibly impressed by the way the Mexican authorities took the news. So coming back with the decision is a joy."

Senard earlier had hosted a groundbreaking ceremony at the 242-acre site in central Mexico, where the French tire company is investing $510 million in what, according to one senior executive, will be Michelin's first greenfield passenger tire plant in North America in three decades.

Senard said the Leon investment is the tire maker's largest anywhere in 2016.

"The last time we launched a greenfield passenger tire plant in North America was over 30 years ago," said Scott Clark, executive vice president and chief operating officer of Michelin North America. "So this is not something we do every day. This is a big deal, and this is exactly the right place to be and at the right time."

The factory, which will employ 1,000 when finished in late 2018, will be within a three-hour drive of 18 car maker assembly plants, he said. It is located in a new industrial park called Leon-Bajio.

The facility will have an annual installed production capacity of between 4 and 5 million Michelin-brand tires, mostly in 18-inch-plus sizes for North American original equipment and replacement markets. The plant's output will "reflect the tremendous growth in the SUV, CUV and pickup markets, followed closely by high-performance tires," Clark said. Most of the replacement tires will go to the U.S. and Canada, he added.

The plant, which will cover 1.5 million square feet, will have its own rubber mixing capabilities, according to the executive—something he said is "not completely unique in the Michelin group."

Asked about possible expansion, he said: "We take it one step at a time. We have almost (240 acres), which is an enormous amount of space. The likelihood of the plant expanding is very high."

Michelin already employs 700 in Mexico, primarily at a factory in Queretaro, 107 miles southeast of Leon, which makes non-Michelin brand tires such as BFGoodrich, Uniroyal, Taurus and Tigar. The plant has an annual capacity of 2 million tires.

Pete Selleck, chairman and president, Michelin North America Inc., said Michelin has "figured out how to operate within Mexico's labor laws, which has given us much more confidence in taking this huge step (in Leon)."

He said "labor issues" forced the company to mothball the Queretaro facility between August 2000 and April 2002.

"We had a situation that was untenable. I was involved. We tried to resolve it."

Closing the plant, Selleck said, was "one of the most difficult decisions" as it meant several hundred jobs were lost.

Referring to the Leon project, known internally as MX2, he added: "I've been with the company for 34 years, and so for me it's very gratifying to see us reach this point."