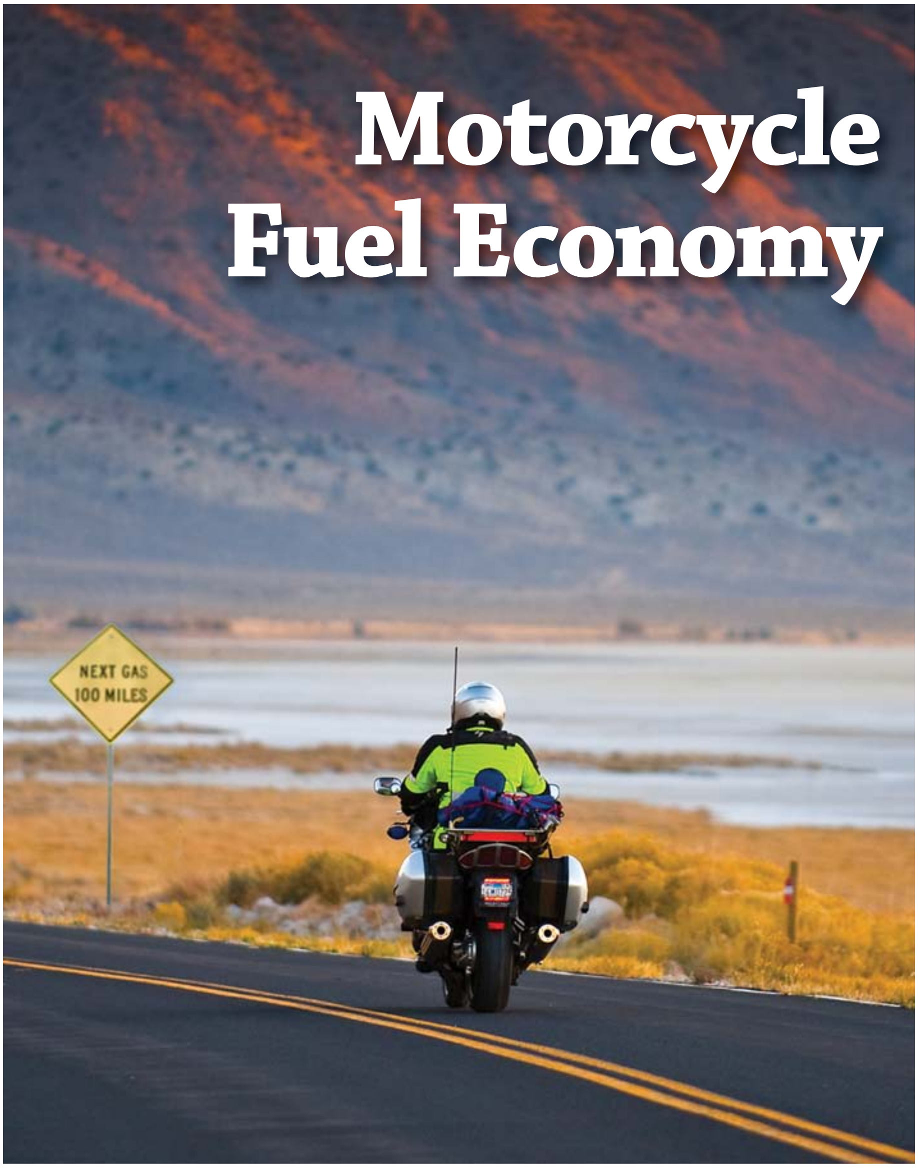
By Tom Austin, IBA Chief Technical Advisor

Motorcycle Fuel Economy



FUEL ECONOMY IS of interest to long-distance motorcycle riders regardless of the price of gasoline and it becomes even more important when prices rise. But information about motorcycle fuel economy is relatively hard to find. Unlike with passenger cars and light trucks, there are no government regulations mandating fuel economy labels on new motorcycles and no regulations specifying the test procedures that should be used. Many motorcycle magazines report the fuel economy achieved when vehicles are tested, but the reported values are not based on carefully controlled engineering tests; results vary based on how hard and how fast a particular bike was ridden.

EPA Test Procedures

Despite the lack of standardized reporting requirements, every motorcycle with an engine larger than 169 cc is required to be tested using exactly the same "City" driving cycle that is used to produce the fuel economy values car and truck manufacturers are required to disclose. That's because it's the driving cycle used to determine compliance with exhaust emissions standards. The test involves stop-and-go driving over a speed range from 0 to 57 mph with an average speed of 19.6 mph. Figure 1 shows the speed vs. time profile for the test.

The driving pattern used for the City test doesn't look much like the typical long-distance motorcycle ride but, for a combination of reasons, fuel economy measured on the EPA City test is close to the level a typical motorcycle achieves cruising at about 70 mph on the highway.

For model years 1985 through 2007, car and truck manufacturers were required to reduce the actual fuel economy value measured during the City test by 10%; it's against the law to report the actual measured value without this adjustment. Since 2008, there is a more complex adjustment required that typically results in the actual test results being reduced by about 20%. The adjustment is required to account for such factors as air conditioning use, operation in cold weather, and other factors that decrease fuel economy in real driving.

A good argument can be made that the adjustments required before reporting City fuel economy for cars and trucks shouldn't be required for motorcycles. So, in the absence of any regulatory prohibitions, some manufacturers

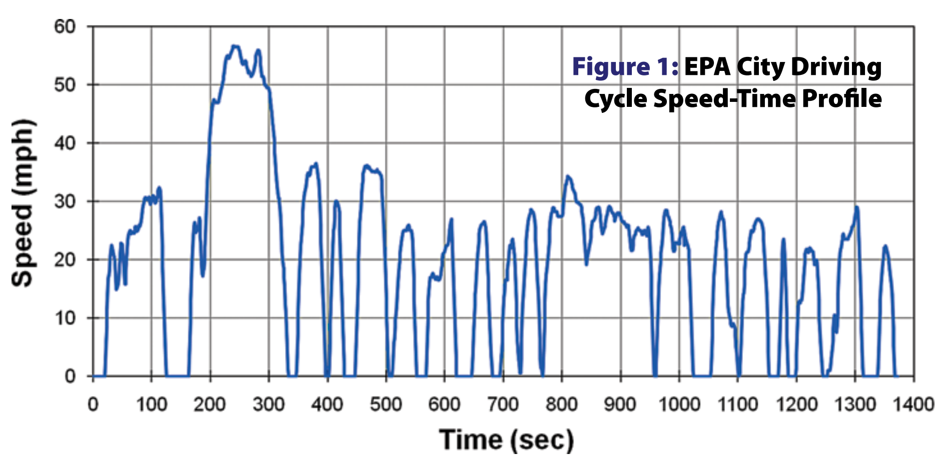


Figure 1: EPA City Driving Cycle Speed-Time Profile

have started reporting "unadjusted" City fuel economy values for motorcycles and scooters.

At the time that I'm writing this, Yamaha appears to have the most comprehensive reporting program, providing City fuel economy values for both scooters and motorcycles. Honda reports fuel economy based on the EPA City test for most scooters and some motorcycles. Suzuki reports what appears to be EPA City fuel economy for some models but not all. Neither Kawasaki, nor Triumph, nor KTM is reporting any fuel economy values.

In a departure from what other manufacturers are doing, BMW and Harley-Davidson are reporting fuel economy values based on both the EPA City test and the EPA Highway test. (BMW also reports fuel economy at steady cruising speeds of about 55 mph and 75 mph, but sometimes the results are listed in units of liters per 100 kilometers, which means nothing to most American customers.) Reporting unadjusted results based on the EPA Highway cycle is misleading because the cycle was developed shortly after the first oil embargo in 1973 and was intentionally designed to reflect vigorous enforcement of a 55 mph speed limit. Fuel economy results obtained using the Highway cycle are therefore substantially higher than can be expected for anyone keeping up with the flow of traffic. To better reflect results motorists can expect in highway driving, EPA required that the actual test results be discounted by 22% until model year 2008. Beginning in 2008, the adjustment is more complicated but generally larger.

Table 1 shows the EPA City fuel economy values being reported for several popular motorcycle models used for long-distance riding. Based on my personal experience with most of these models, the reported values are quite reasonable.

Table 1: Popular Motorcycles for Long-Distance Riding

Model	lbs	CCs	"City" MPG
BMW R1200RT	570	1170	43
BMW R1200GS	504	1170	43
BMW K1200LT	853	1172	41
Yamaha FJR 1300	644	1298	39
Honda Gold Wing	928	1832	36
Honda ST1300	719	1261	37
Suzuki DL1000 V-Strom	525	996	40
Suzuki DL650 "Wee Strom"	478	645	51
HD Electra Glide	889	1573	35

Factors Affecting Fuel Economy

As shown in Table 1, the lighter-weight vehicles with smaller engines tend to have higher fuel economy. All other things being equal, lighter vehicles with smaller engines do have higher fuel economy, but it's a bit more complicated than just that. Table 2 lists the primary factors affecting fuel economy. As shown, there are two types of factors: factors that affect power demand and factors that affect the efficiency with which the required power is delivered to the drive wheel. Highest fuel economy is achieved by simultaneously reducing power demand and increasing the efficiency with which the required level of power is developed.

Table 2: Factors Affecting Fuel Economy

POWER DEMAND
- Vehicle Speed
- Frontal Area and Drag Coefficient
- Weight
- Tire Rolling Resistance
- Acceleration Rate

POWER TRAIN EFFICIENCY
- Engine Size
- Throttle Opening
- Engine RPM
- Compression Ratio
- Transmission Efficiency

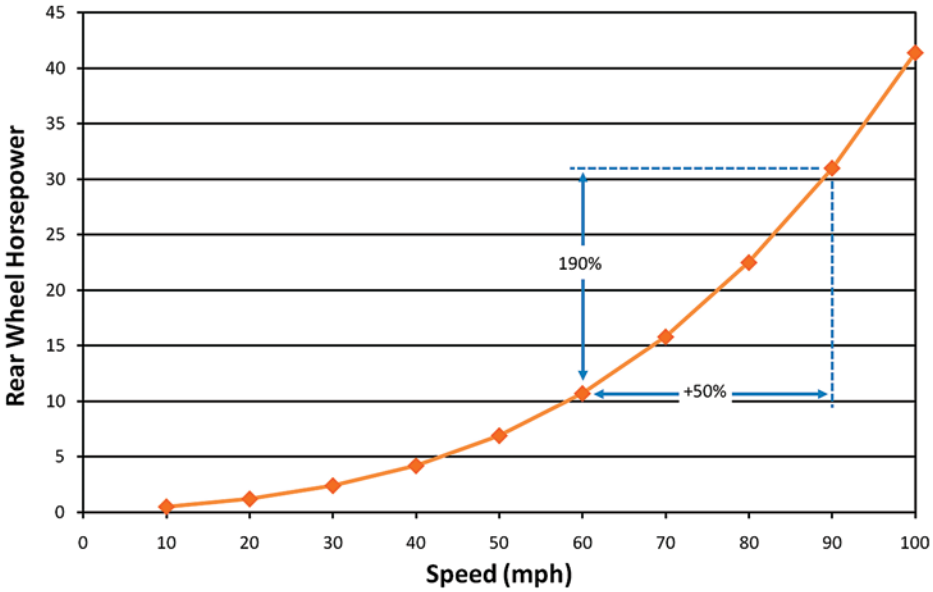
POWER DEMAND: The following equation shows how speed, frontal area, aerodynamic drag coefficient, acceleration rate, weight, and rolling resistance affect the power (in kilowatts) required to propel a motorcycle on a level road.

$$Power = \frac{[(C_{rr} \times W \times g) + (0.0386 \times \rho_{air} \times C_d \times A_f \times v^2) + (W \times a)] \times (v)}{3.6 \times 10^6}$$

Where:
C_{rr} = coefficient of rolling resistance (dimensionless)
W = loaded vehicle weight in kilograms (kg)
g = universal gravitational constant (9.81 m/s^2)
ρ_{air} = air density in kg per cubic meter (1.225 kg/m^3 at sea level)
C_d = coefficient of aerodynamic drag (dimensionless)
A_f = frontal Area in square meters (m^2)
v = velocity in kilometers per hour (km/h)
a = acceleration rate in meters per second^2 (m/s^2)

What this rather complicated equa-

Figure 2: Power Demand vs. Cruising Speed (Gold Wing)



tion shows (trust me) is that the power required to overcome aerodynamic drag increases exponentially with speed. In other words, it takes more than twice as much power to go twice as fast. For this reason, higher speeds dramatically reduce fuel economy.

Figure 2 is a graph showing the relationship between cruising speed and power demand for a Honda Gold Wing. As shown in the graph, the power required at 90 mph is 190% higher than the power required at 60 mph although the speed at 90 mph is only 50% faster than the speed at 60 mph. This means that you are going to burn a lot more fuel per mile of travel if the engine efficiency is about the same at each speed.

POWER TRAIN EFFICIENCY: As shown in Table 2, the factors that affect the efficiency with which power is produced include engine size, throttle opening, engine rpm, compression ratio, and transmission efficiency. As discussed in more detail below, several of these factors are inter-related. However, to achieve the highest efficiency, you want the smallest engine, running with the largest throttle opening, at the lowest rpm, with the highest compression ratio, and an efficient manual transmission.

Engine size, engine rpm, and throttle opening are all related. The larger the engine, the less the throttle will need to be opened to provide the required level of power. A lower throttle opening results in higher intake manifold vacuum. Since the tops of the pistons are exposed to manifold vacuum on the intake stroke, the vacuum is a drag on the engine. The power required to overcome the vacuum is called "throttling loss." A smaller engine is more efficient because the throttle has to be opened wider to achieve the same power output, which reduces the vacuum and the throttling loss.

Engine speed also affects throttling loss. If the gearing is such that the engine is running slower, the throttle needs to be opened wider to achieve the required power output and throttling loss is reduced. Lower engine speed also results in lower frictional losses.

Higher compression ratio increases engine efficiency by allowing greater expansion of the burned gases before the exhaust valve is opened. A side benefit of higher compression ratio is that the engine also produces more power; for equivalent power, the engine size can be reduced, which reduces throttling losses.

The higher the efficiency of the transmission and other drive train components (e.g., chain), the less fuel must be burned to produce the required level of power at the rear wheel.

Effects of Speed and Gearing

Figure 3 shows fuel economy over a range of cruising speeds for a Honda Gold Wing. (The results values plotted in the figure were produced using a "vehicle simulation model," a tool generally available only to vehicle manufacturers that can accurately estimate the effect of driving conditions and design changes on fuel economy.) At 60 mph, the fuel economy is 48.3 mpg. At 90 mph, the fuel economy drops to 28.7 mpg.

This loss in fuel economy is slightly less than would be predicted from the difference between the 190% increase in power required at 90 mph and the 50% increase in speed. The higher throttle opening required to produce the power required at 90 mph actually makes the engine more efficient (despite the higher

Figure 3: Fuel Economy vs. Cruising Speed (Computer Simulation of Gold Wing)

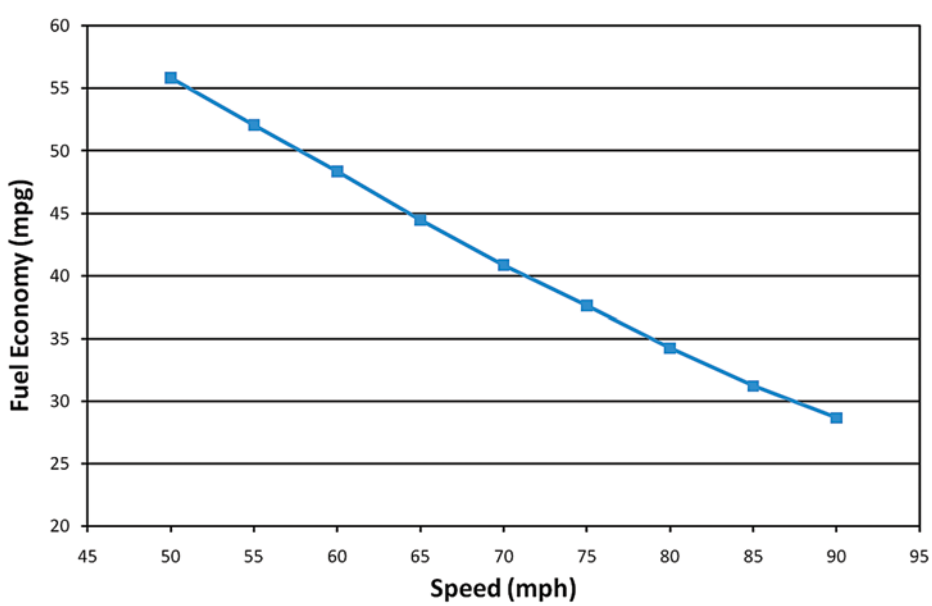
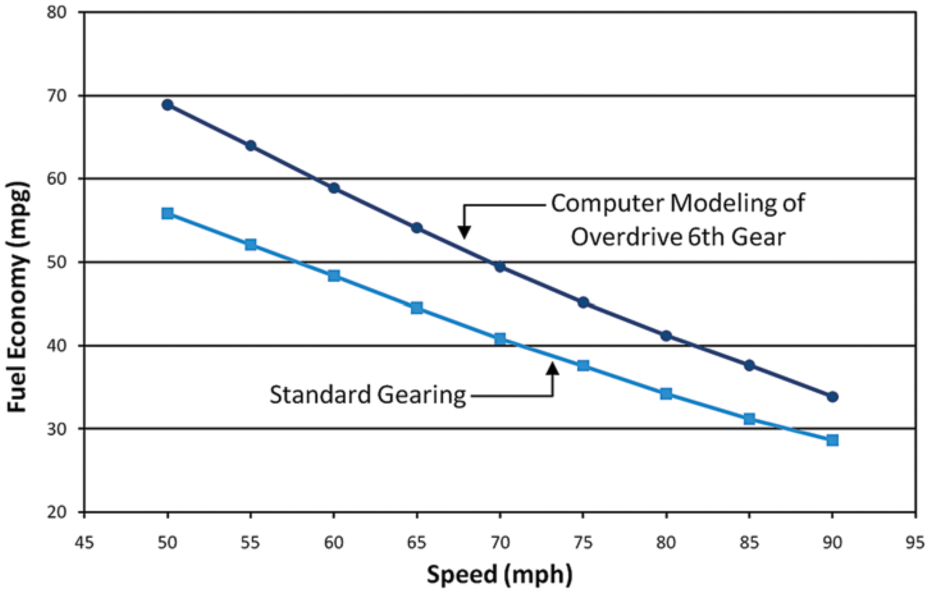


Figure 4: Effect of Gearing on Fuel Economy (Computer Simulation of Gold Wing)



rpm) and reduces the loss in fuel economy associated with the higher power required.

Figure 4 shows how the use of taller gearing would affect fuel economy. With standard gearing, the Gold Wing is running just under 3,000 rpm at a true 70 mph and getting 40.9 mpg. The upper curve on the graph shows how the fuel economy would change with the addition of a 6th gear that reduces engine speed by 40%. At 70 mph, the engine speed is reduced to just under 1,800 rpm. Friction losses are reduced and the throttle has to be opened wider to achieve the required power level, which reduces throttling losses. Engine efficiency improves enough to increase the fuel economy to 49.5 mpg.

So why doesn't Honda add a 6th gear to the Gold Wing and increase the 70 mph fuel economy to almost 50 mpg? Probably because the first road test of the new model would result in complaints about poor "roll on" performance in top gear. Journalists would complain that downshifting is required to safely pass slow moving vehicles.

Because fuel economy has historically been a very low priority for most motorcyclists, manufacturers have generally used performance-oriented gearing and riders have come to expect strong acceleration in top gear at highway speeds. From a rational point of view, a Gold Wing with an additional, taller top gear would be terrific: 21% better fuel economy with the *same* acceleration performance available just by downshifting. But most riders haven't been conditioned to think this way, so almost all motorcycles burn way more fuel than they need to on the highway because of the way they are geared.

The Honda Gold Wing actually has taller, more fuel-efficient gearing than most motorcycles. Most other motorcycles could experience even greater benefits from a taller top gear. The BMW K1300GT is a case in point. From the point of view of an automotive engineer with an interest in fuel economy, this bike has ridiculously short gearing. The new BMW K1600GT is a bigger bike, with more power, and better acceleration performance from a standing start, but it gets better fuel economy than the K1300GT because it has a taller top gear. Sure enough, in one of the first road tests of the K1600GT, the journalist complained that top gear acceleration performance was not a good as the K1300GT.

Tips for Achieving Higher Fuel Economy

As noted above, there is a limited amount of fuel economy information available on manufacturers' websites that can be helpful in deciding which motorcycle to purchase in the first place. For example, it's good to know that the Suzuki DL650 Wee Strom gets 27.5% better fuel economy than the DL1000 when trying to decide between these two models. But after a purchase decision has been made, there are still things a rider can do to improve fuel economy.

LIMIT MAXIMUM SPEEDS: As shown in the above figures, higher cruising speeds have a big effect on fuel economy. Without exception, all motorcycles get better fuel economy when cruising at lower speeds. Peak fuel economy typically occurs at 30-35 mph. This is obviously an impractical and unsafe speed for the highway, but the point is that slower is always better as far as fuel economy is concerned. Fuel economy at 70 mph is typically about 20% higher than at 80 mph.

AVOID HIGH RPMS: For any given vehicle speed, higher fuel economy is achieved by using the lowest possible engine speed. To accomplish this, upshift as soon as possible and always use the highest gear that will do the job, whether cruising at a steady speed or passing.

MINIMIZE BRAKES: It's often said that "jack rabbit starts" are bad for fuel economy. But a high rate of acceleration is not a problem as long as you upshift early. What really hurts fuel economy is the use of your brakes. Brakes destroy forward momentum by turning it into heat; restoring that lost momentum requires more fuel to be burned. Get off the throttle early when approaching an intersection at which you must stop to minimize the use of your brakes.

MINIMIZE FRONTAL AREA: When accessorizing your motorcycle, install windscreens, luggage, and auxiliary lights in a manner that minimizes the effect on frontal area. If possible, for example, install auxiliary lights in front of a fairing instead of sticking out in the air stream. Don't use the widest available windscreen unless you really need it.

MINIMIZE WEIGHT: Weight has a big effect on fuel economy in stop-and-go driving, but relatively little effect at steady cruising speeds. However, there is still a benefit to carrying no more weight than is absolutely necessary.

MAINTAIN PROPER TIRE PRESSURES: Low tire pressures increase rolling resistance and reduce fuel economy. Always keep your tires properly inflated.

AVOID ALCOHOL-GASOLINE BLENDS: Alcohol-gasoline blends, such as "Gasohol" (10% ethanol) have lower energy content and therefore reduce fuel economy. A blend with 10% ethanol reduces fuel economy by about 3%.

If you have specific questions about fuel economy, send an e-mail to austin@ironbutt.com.

Are We Running Out of Oil?

IN 1919, THE head of the U.S. Geological Survey (USGS) predicted that oil production would peak by 1928 and decline thereafter. Two fundamental mistakes contributed to this erroneous prediction: (1) a gross underestimate of the total volume of oil in the Earth's crust, and (2) a failure to recognize the progress that would be made in oil production technology. Since then, the same mistakes keep being made.

Many have heard the term "Peak Oil" used to describe current production levels and their impending decline. The term describes work done over 50 years ago by a geologist working for Shell Oil. In 1956, Marion King Hubbert used then-current estimates of extractable fossil fuel resources with predictions of energy consumption trends and concluded that U.S. oil production would peak between 1965 and 1970 and global oil production would peak in 2000. Because U.S. production has declined since 1971, there is widespread popular acceptance of the proposition that Hubbert's predictions were only slightly pessimistic and that there is a looming energy crisis associated with soon to be declining oil production.

But Hubbert made the same mistakes that the USGS made in 1919; he underestimated the size of the resource base and he failed to recognize the progress that would be made in oil production technology. One of the reasons that oil resources continue to be underestimated is that, contrary to popular opinion, oil isn't made from dead dinosaurs — it's made from dead plankton. That's why so many new oilfields are found offshore. (Onshore oil fields are located in what used to be ancient sea beds.) As the technology evolves to extract oil from deeper waters that are farther off-shore, the size of economically recoverable oil reserves continues to grow.

When Hubbert predicted global oil production would peak in 2000, he expected the peak production rate to be 13 billion barrels per year. In contrast, current production levels are about 30 billion barrels per year. By 2035, the U.S. Energy Information Agency quietly projects the global production rate on "conventional" liquid fuels will increase to over 35 billion barrels per year. Even at that increased rate of consumption, the already proven reserves of conventional and unconventional oil (e.g., shale) will last for more than 50 years. When oil resources now estimated to be "potentially recoverable" are considered, the supply increases to over 100 years (based on estimates published by the World Energy Council).

The above forecasts are based on what we know today. They have to be viewed in the historical context of how long we thought fossil fuels would last based on what we knew in 1919. The techniques we have developed for extracting fossil energy resources are literally just scratching the surface of what exists in the Earth's crust. We now know that there are vast deposits of methane hydrates (essentially frozen natural gas) that greatly exceed the estimated reserves of all other hydrocarbons combined, including oil, shale, and coal. We don't yet have the technology to economically extract these vast resources and convert them into liquid fuels, but at the time of the first oil embargo, we had no idea that such a vast resource even existed.

Given the additional options available for making liquid fuels from coal, biomass, and even from nuclear energy (used to separate hydrogen from water), it's clear that we are never going to run out of oil. We will continue producing fuels from oil until our technology develops to the point that another resource becomes more economical. The current concern about the depletion of resources will undoubtedly seem rather silly to our ancestors in the next century.

Finally, it is important to recognize that recent variations in the price of oil have nothing to do with the actual cost of production. The most expensive oil being produced today still costs less than $40 per barrel to produce. Substantially higher prices are purely the result of imbalances in supply and demand that are largely the result of political factors, including government-imposed prohibitions on developing known resources in desolate areas like the Arctic National Wildlife Refuge.