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An Innovative Path to Sustainable Transportation

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I am honored and humbled to accept the prestigious Blue Planet Prize. I gratefully thank the Asahi Glass Foundation for its leadership in recognizing the importance of global environmental problems and for encouraging those of us seeking solutions.

The world is getting richer. Over one billion people have risen out of extreme poverty in the past 20 years. We are healthier and better educated than any time in history. But another 2 billion remain hungry, uneducated, and without access to basic services. Today, more than any other time in history, we have the ability, the means, and the motivation to eradicate poverty and to elevate billions into the middle class.

Meeting that challenge and growing more affluent means more consumption of resources. If this consumption continues to be based on current unsustainable forms of energy, it would lead to another crisis—climate change—which not only threatens to reverse our hard fought gains, but also threatens the future of the human race.

By 2050, the Earth will be occupied by over 9 billion people. Today, approximately one billion of those live in today's rich countries of Europe, North America and Japan. If the other 8 billion follow the same consumption pattern, the current 1.2 billion vehicles will become 6 billion by 2050, dramatically increasing the global consumption of high-carbon fossil fuels. Greenhouse gas emissions will soar. This five-fold increase could be calamitous, especially for less affluent countries, who are ill prepared for major climate disruptions.

Therein lies our challenge—can the wealthy countries not only curb their appetite for fossil energy, but also be leaders in developing and adopting new low-carbon life styles? Can we help emerging countries create environmentally sustainable economies and lifestyles that allow them to join in the prosperity and enjoy a high quality of life?

A new paradigm is needed that allows for more consumption and mobility, but without disrupting ecosystems, altering the climate, depleting water supplies, extinguishing species, and poisoning our air, land, and water.

Humans are incredibly creative. When motivated, humans respond vigorously and effectively. Earlier predictions by Malthus and others about unsustainable resource demand have been proven wrong. When given the incentive to innovate, we make miraculous inventions and reorganize our cities and economies. Innovations of the past few decades are particularly impressive. Advances in materials and digital communication have transformed industries and lifestyles. Personal computers, the internet and now smart phones have enriched our lives, boosted our productivity and increased entrepreneurial opportunity.

Creativity plus political resolve also generated other environmental benefits, including dramatically cleaner air and water in the cities of Japan, US and Europe. These improvements came about because humans focused their creativity and resources on the goal of eradicating pollution. There is still much to do, but let's take heart that much has already been accomplished.

Climate change is a much bigger challenge. Local air pollution was dealt with by adding technical fixes to cars, trucks, factories, refineries, and power plants, or by moving the pollution source to other regions of the world. Industries that could not or would not make these changes moved to less regulated regions eager for economical opportunity. Today many of those regions face serious pollution challenges. Climate change requires a whole new level of skill and commitment: not just technical fixes, but also transformation of entire industries and our built environment.

I will focus on one sector of our society—transportation—a topic to which I have devoted my career. We know that the transportation sector contributes 20% of the greenhouse gas emissions in the world. The fundamental challenge is that (high energy-consuming) cars and trucks now dominate transportation. Cars provide incredible mobility, comfort and convenience. And trucks have the flexibility to carry goods almost anywhere on land, from any origin to any destination. I am from California, where car-centric cities and lifestyles were pioneered, where cars and trucks now account for 40% of the greenhouse gas emissions. The challenge is to reverse trends and patterns of the past 100 years, and move to more sustainable transportation technologies and behaviors. The one billion people who have benefitted economically from abundant fossil energy must embrace and champion the innovation and changes needed to create a carbon-neutral future.

Change is urgent. Humans have released about 1400 gigatons of CO₂ over our entire history. Climate scientists conclude that emitting another 500 gigatons will raise the global temperatures about 2 degrees (centigrade). With a 2 degree increase, climate disruption is likely but serious catastrophes would likely be averted. But even limiting the temperature increase to 2 degrees is probably not possible. The world is currently emitting about 31 gigatons of CO₂ per year. If we continue at this rate, we will reach the 500 gigaton threshold in only 16 years! We would then need to drop global emissions to zero immediately to avoid the threat of climate catastrophes—an impossibly abrupt transformation. This simple projection means that the world needs to begin reducing emissions immediately.

A sharp reduction in emissions is only possible if much of the fossil energy in the Earth's crust stays there. As Sheik Zaki Yamani, oil minister for Saudi Arabia from 1962 to 1986, said, "The Stone Age came to an end not because we had a lack of stones, and the oil age will come to an end not because we have a lack of oil." But how can we slow and eventually stop the use of fossil energy, given the relatively small amount of time available to us?

We need to do the following:

1. Devise a new model of development to replace the obsolete car-centric paradigm that has dominated the last 50-100 years.
2. Pursue a portfolio of technological and institutional innovations, with the mix and details tailored to each city, region, and economy (with no need to wait for entirely new inventions).
3. Start reducing emissions immediately.

4. Acknowledge desirable end-state visions, but focus on incremental approaches rooted in no-regrets strategies and desirable pathways of change.
5. Help researchers engage much better in bringing science to policy—aiding local, regional, and national communities and governments who desperately need help in implementing effective and acceptable innovations.

It is easy to imagine an end-state future based on renewable energy—it is desirable and indeed inevitable. But how do we get from today’s fossil energy world to one based on sun, water, wind and plants? How do we wean ourselves off fossil energy and rebuild our cities and transportation systems to be far more energy efficient? How do we transform an economy and society that currently depend primarily on oil, natural gas, and coal for energy, where people desire high levels of mobility and living space, where cities have sprawled to accommodate desires for more mobility and space, and where huge, powerful incumbent industries and consumers resist change?

LIKELY CONDITIONS AND TRENDS

Contrary to wishful thinking by many, the transformation of business, lifestyles, and cities is unlikely to be motivated by high fossil fuel energy prices. The prices of oil and other fossil fuels are unlikely to jump to another level. Indeed, most global energy and carbon emissions forecasts are premised on oil prices of about \$100 to \$150 per barrel—not much higher than today’s prices. Prices might be even lower. New exploration and extraction technologies are making it cheaper and easier to extract fossil energy. The most recent example is increased oil supply from US shale and Canadian oil sands. Another downward pressure on oil prices is the worldwide embrace of aggressive fuel efficiency standards for vehicles.

In the past, OPEC would have responded to downward price pressures by reducing production. That is becoming less likely for the simple reason that most OPEC countries need those funds for social programs and subsidies to discourage political uprisings. Most depend on oil revenues for over half their national budgets. In other words, there is as much of a chance that prices will drop below \$100 per barrel as there is a chance they will soar over \$150.

The overriding conclusion is that we cannot depend on high oil prices to dampen the forecasted increases in transport energy use and GHG emissions. Because we cannot depend on oil prices to reduce transport oil use and GHG emissions, we need a broader mix of strategies. We can untangle this mix of strategies but thinking of transportation as a three-legged stool, comprising vehicles, fuels, and mobility (where mobility takes account of land use patterns and infrastructure).

I’ll inflict only one formula on this audience, and this is it:

$$\begin{aligned}
 &\textbf{Total greenhouse gas emissions =} \\
 &\textbf{Vehicle Travel Demand (vehicle kilometers traveled per year)} \\
 &\quad \textbf{x Vehicle Efficiency (liters/100km)} \\
 &\quad \textbf{x Carbon Intensity of Fuel (gCO2/MJ)}.
 \end{aligned}$$

I will address trends for each of these—vehicle demand, vehicle efficiency and fuels—and then explore strategies for shifting those trends in a more sustainable direction.

1. Vehicle Travel Demand: Heading Toward a Car Monoculture.

The first leg of the transportation stool is vehicle travel demand. In the US and many other rich countries—and increasingly in emerging economies—personal cars have nearly vanquished all competition in metropolitan travel. The United States is the most extreme case, but others are following. In the US, public transport, including all buses and rail service, now accounts for less than 3% of passenger kilometers traveled. Bicycles and walking account for less than 2%, and air travel for about 10%, virtually all for long intercity trips. Light duty vehicles—cars, minivans, sport utility vehicles, and pickup trucks—account for almost all of the rest—about 85%--the vast majority with a single occupant.

Metropolitan passenger travel in the US, and increasingly elsewhere, is essentially a monoculture. Most people, upon arising in the morning, mindlessly enter their vehicle for their day's travel. They do not contemplate what mode they use. The car does not dominate to the same extreme in other rich countries, but those others are following the same path. In the 27 countries of the European Union, public transport now accounts for only about 16% of passenger kilometers traveled, and somewhat more in Japan. Walking accounts for about 20% of trips in much of Europe and Japan, though the trips are short and thus account for only a few percent of total kilometers traveled. In any case, other countries, with few exceptions, are following the same motorization path as the US, building more expressways to accommodate more cars.

What we have is a passenger transport system that has barely changed in a functional sense in over 60 years. Yes, cars are much higher quality—more durable, reliable, safe, and comfortable—but cars still operate at about the same speed, have the same size and capacity, use four wheels, and are powered by an internal combustion engine fueled by petroleum. Highways are also essentially unchanged. There are more limited-access roads and they are safer, but roads remain largely free, serve all vehicle types, and provide roughly the same level of service as decades ago. Transit services are also essentially unchanged. Buses are now air-conditioned, but otherwise nearly identical in operations, capacity, and performance. Most large cities now have modern rail transit, including partially grade-separated light-rail systems and heavier, fully-grade-separated systems. But in the US all types of rail transit carry less than 1% of passenger kilometers, most of it on century-old technology with only minor upgrades. Even in Europe, rail transit carries only 7% of passenger travel, while Japan performs somewhat higher with about 12%. Innovation is clearly lacking. The concept of bus rapid transit, whereby buses operate in platoons over dedicated right-of-way, is one of the few significant innovations.

Today's passenger transport system is extraordinarily expensive, not just to society but also to the users. It now costs about \$9,000 per year to own and operate a car in the US, and even more in most other countries. Land-use densities have dropped virtually everywhere in the world. Homes are getting larger, increasingly surrounded by lawns. All of this was accelerated by widespread availability of vehicles. Car-centric suburbanization was pioneered in Los Angeles and spread from there. With sprawling land-use patterns and falling densities, vehicle ownership has now reached 0.8 vehicles per person in the US, with more than half of all households owning 2 or more vehicles.

The good news is that car ownership and use seem to have stabilized and are showing signs of dropping in most rich countries. It is still too soon to know how much of this effect is due to the economic recession, shifting preferences, and more livable urban cores, but evidence is mounting that the trend toward more cars and more driving is now ending. Importantly, peak levels in Europe and Japan are far lower than in the US.

2. Fuels: The Trend Toward Greater Carbon Intensity

We are not going to run out of oil—not for many centuries. Or at least, we’re not going to run out of fossil energy to make gasoline and diesel fuel. There are vast amounts of unconventional oil—heavy oils, oil sands, shale oils, and even coal that can be converted into transport fuel—for less than \$100 per barrel. Unfortunately, these unconventional fuel sources will greatly increase carbon dioxide emissions because they require far more energy to extract and refine than conventional oil. Oil companies are already investing hundreds of billions of dollars in unconventional oil production, for two reasons: they are essentially large engineering companies whose core competencies are best suited to building mammoth projects (as opposed to small renewable projects); and OPEC countries have cut off access to the most abundant and best oil reserves.

The big oil companies are seeing their most secure reserves dwindle—those located in open economies such as the United States, Canada, and the European Union. They’re losing control of oil reserves elsewhere as oil-rich countries increasingly turn away outsiders and nationalize oil reserves under the control of their state-owned companies. The large international oil companies need to replace these resources to survive. Their solution is to embrace unconventional fossil energy—to convert oil sands, heavy oil, coal, and shale into liquids. These unconventional sources of fossil energy are abundant in North America, Asia, and even parts of Europe. These resources can be converted into petroleum-like transportation fuels. It’s already happening. It fits perfectly with the corporate culture and core capabilities of Big Oil, since building huge petrochemical facilities and aggregating huge amounts of capital are exactly what’s needed to develop unconventional oil sources. But there are big downsides to unconventional fossil sources: they pose dire environmental threats, including a surge in carbon dioxide emissions. Left to itself, the oil industry will invest far more in high-carbon unconventional oil than low-carbon alternative fuels.

Petroleum will undoubtedly reign supreme for decades to come. But there have been many transportation energy contenders. Methanol and compressed natural gas were promoted in various places in the 1980s, but mostly discarded when oil prices dropped and air pollution benefits were found to be modest. Electric vehicles succumbed the first time around in the early 1900s and again in the early 1990s, unable to overcome the high cost of batteries and the limited range of vehicles. Hydrogen followed in the early 2000s, receding when the high initial cost and absent fuel stations were highlighted. Then came biofuels later in that decade, but it soon was recognized that using food to make energy was undesirable, though corn-based ethanol retained its foothold because of its large farm constituencies.

Replacing petroleum will be difficult and slow. The hegemony of petroleum creates huge barriers for new fuels—in terms of economics, liability, public skepticism, and media sensationalism. Alternative fuels will unquestionably play an expanding role, but all face large challenges. None will be easy.

The oil market is clearly not functioning efficiently nor rationally. No one knows what the price will be, and

most investment continues to reflect business-as-usual thinking. Market information is unreliable, price forecasts are guesses, and most oil producers are barely responsive to market conditions. Perhaps worst of all, climate change and the public interest are being ignored.

3. Vehicles: An Emerging Energy-Efficiency Success Story

The third leg is the strongest and most promising for the next few decades. Aggressive policy is in place in most of the major car markets, including Europe, the US and Japan, to cut fuel consumption in half (per vehicle) in the next 15 years. Many other countries have adopted similarly aggressive efficiency improvements, or are in the process of doing so, including China. Importantly, the international auto industry has embraced these regulatory requirements, making efficiency their top priority. They are using more lightweight materials, improving transmissions, increasing combustion efficiency, improving aerodynamics, and hybridizing the combustion power trains with electric motors. And all of them are slowly embracing vehicle electrification—pure battery electric vehicles, plug-in electric hybrids, and hydrogen-powered fuel cell electric vehicles. By 2035, a large proportion of new vehicle sales around the world are likely to be plug-in and fuel cell vehicles. Light duty vehicles are already on a trajectory that plausibly leads to 80% reduction in their greenhouse-gas emissions (per vehicle kilometer) by 2050.

While cars are a big success story, trucks are not. Efficiency improvements are much slower, though new regulations are in place in Europe, the US and Japan and there is some possibility that these standards will be tightened in the near future. But more challenging is their unsuitability to most low-carbon energy alternatives. Trucks are heavy and tend to travel long distances each day. Most trucks cannot be easily powered by electricity because batteries are very heavy and bulky. Batteries only work well on small vehicles that do not travel far. Fuel cells are possible with trucks. While hydrogen fuel tanks and fuel cells are much bulkier than diesel fuel, they are far lighter and smaller than batteries. The best long-term energy option for trucks will probably be low-carbon biofuels.

Summary of Trends

The near-term prospects for surface passenger transportation are mixed. Vehicles are becoming far more efficient and next-generation technology—battery and fuel cell electric vehicles—are at hand and look promising. But the other two legs of the stool are less promising. While vehicle use is flat or subsiding in most rich countries, it is skyrocketing in emerging countries. If emerging and less developed countries follow the car-centric pattern of development pioneered in the US, then the energy efficiency improvements in vehicles will be swamped by the flood of vehicles. Rapid increases in air travel, which I have not addressed here, also threaten large increases in energy use and greenhouse gas emissions.

The third leg, fuel de-carbonization, is equally challenging, for both passenger and goods movement. The transition to low-carbon electricity, hydrogen, and biofuels is threatened by the preference of oil suppliers to invest in unconventional oil (shale oil, oil sands, heavy oil), which is much more carbon intense.

The greater transportation challenge is goods movement. It has fewer technology and fuel options, and policy is lagging. Trucks are not well suited to battery electric power. Hydrogen-powered fuel cells may prove attractive, but biofuels made from non-food sources seem the most likely energy option for sharply reducing GHG

emissions from trucks and ships. Exacerbating the challenge is continuing increases in truck use almost everywhere—due in large part to sprawling land use patterns—with almost no policy in place to restrain that trend. Most forecasts anticipate that by 2050, trucks, planes and ships will consume more energy and emit more GHGs than cars.

CHALLENGES OF GETTING FROM HERE TO THERE

It is easy to craft future visions of a sustainable transportation system. I have done so myself in various papers and books. Others have also. In an idealized future, we would drive small electric vehicles in our neighborhoods, and for longer trips would use our smart phones to beckon energy-efficient hydrogen-powered fuel-cell transit vehicles to pick us up and deliver us. We might also drive small vehicles on electrified, lightweight, overhead tracks, and then depart from those tracks using a small battery in the vehicle to access more remote locations. Planes and trucks would operate on low-carbon biofuels, trains would operate on renewable electricity, ships would operate on hydrogen fuel cells or biofuels, and local goods delivery would be made by small electric or fuel cell trucks. Perhaps more advanced technologies will also become widely available, including magnetically levitated vehicles and advanced vacuum tubes.

This envisioned system could provide travelers with high levels of mobility and accessibility, radically reduced energy use and emissions, and costs similar or even less than today's transport services. Including goods movement, one can craft a plausible plan where total GHG emissions for all of transportation is 80% lower than today.

That is a good vision. I have learned that crafting visions is important in focusing public attention on what is possible and what transformations are needed. But far more important and far more challenging is to craft pathways for how to get from here to there—to determine the incremental steps that must be taken now that will put us on a path headed in the right direction to eventually achieve desirable long-term outcomes.

Now I will discuss three key phenomena for moving incrementally forward in the right direction.

1. Beyond Car-Centric Cities: Mid-Course Corrections for Rich Cities and New Models for Emerging Economies.

Los Angeles pioneered car-centric cities and lifestyles 100 years ago. One of every 3 Los Angeles residents owned a car by 1930. The rest of the world followed, with Europe reaching those car ownership levels 30 years later, and Japan 40 years later. But that model is now widely recognized to be unsustainable and undesirable, even in California where a 2008 law calls for a reduction in vehicle use. A new model is needed, especially in those places with rapidly expanding economies. Some will have great trouble backtracking, such as Beijing, which enthusiastically embraced the car-centric model, recently building a massive network of expressways and a culture of car ownership. It already has more than one vehicle for every 4 people. Other cities in Asia, Africa, and Latin America have more time to pursue a different vision.

While cities in rich countries are now largely locked into car-centric development, they still have much opportunity to reduce car use through better land-use planning, expansion of innovative mobility services, and full-

cost pricing of vehicles, fuels, roads, and parking. And they can also shift to smaller vehicles for many trips and uses.

For all cities, there is a great opportunity to use modern information and communication technologies to provide more and better mobility services, and to manage traffic, parking, and public transportation better.

Traffic management could be improved dramatically by combining better data gathered from sensors and other devices with more creative and rational management using pricing. These are new ideas but are rarely implemented.

Perhaps most novel would be creation of a suite of new mobility services to fill the gap between single-occupant cars and conventional bus and rail transit. These include demand-responsive transit services, whereby vans and small buses respond immediately to trip requests made by smart phone (or internet connection), and smart carpooling, whereby travelers located near each other self-organize carpools in real time, perhaps to commute to and from work or to attend major recreational and social events such as ball games. Also included here is car sharing and bike sharing, along with the use of small neighborhood cars for local travel. Given the high cost of owning and operating cars—roughly \$9000 per year in the US and more where fuel prices and vehicle taxes are higher—creation of a broader portfolio of mobility services creates the potential for more efficient, less expensive, and less resource-consumptive passenger travel.

Again, these are not original ideas; indeed, all of these concepts are already being implemented. Many start-up companies are offering these new mobility services, some companies sell neighborhood cars, pricing is used in a number of cities to manage traffic flows and parking, and bus rapid transit is being embraced in many cities. But these are generally fragmented initiatives in scattered cities.

Leadership is needed to create more sustainable passenger transportation. Leadership is needed that appreciates the many co-benefits of these various initiatives—including less infrastructure cost; more equitable and broader access to transportation services; less local pollution, energy use, and greenhouse gas emissions; and generally more livable communities. Political leaders can focus on whichever benefits resonate best in their communities. Ironically, one of the most innovative policy responses is in my home state of California, where car-centric living and cities were pioneered. Its “Sustainable Communities Act” of 2008 imposed a greenhouse gas target on passenger travel and is helping transform thinking about livability, the benefits of restraining sprawl, and the desirability of modifying the built environment to reduce motor vehicle use and increase walking and bicycle use.

2. Overcome *Fuel du Jour* Phenomenon

One of the most stubborn challenges is the fuel du jour phenomenon, whereby politicians and the media embrace and hype new transportation fuels, only to quickly discard them when they cannot meet the high expectations.

Now electric vehicles are being hyped again. They certainly provide large attractions, but will the short attention span of politicians and media again kill off an attractive option—before it has time to gain consumer

acceptance, build scale economies, benefit from learning-by-doing, and fully implement supportive policies? Policy is especially critical. Without strong policy, unconventional petroleum fuels will sweep aside all alternatives, including electric vehicles.

The most promising fuels are those that will remain standing when all economic and environmental criteria are considered—almost certainly low-carbon electricity, hydrogen, and biomass. If carbon capture and storage proves effective and acceptable, hydrogen derived from coal might also prove attractive.

Hydrogen probably has the potential for replacing the most petroleum, but it faces the greatest start-up challenges. Electricity also has great potential and is appealing on environmental and energy grounds, but it's stymied by the shortcomings of batteries. Biofuels will certainly play a role, but their future depends on developing new methods of producing fuels, discovering new types of genetically modified organisms, finding and utilizing large amounts of waste biomass material, and avoiding competition with food.

All have their limitations, but all hold the potential to replace large amounts of oil and to reduce or even eliminate greenhouse gas emissions. The challenge is to put in place strong policies to reward and support those that are most compelling. Durable performance-based policies such as the low carbon fuel standard in California (and related policies in Europe and British Columbia, Canada) that reward carbon reduction are promising, especially when accompanied by incentives that help boost initial investments in hydrogen stations and advanced biofuel technologies.

3. Embracing Vehicle Electrification

Vehicles are becoming lighter and more efficient and, importantly, relying increasingly on electric power. This electrification is key to the long term sustainability of vehicles. The process is incremental and evolutionary. The simplest form of vehicle electrification is use of stop-start power, whereby an engine turns off when a vehicle pauses or slows, and uses an enlarged battery to capture energy otherwise lost from braking as electricity. Many new vehicles already have this capability. Next on the technology spectrum is on-board hybridization, whereby an electric motor helps propel a vehicle, drawing electricity produced on-board from the engine and using a battery to store and buffer electricity. Honda and Toyota pioneered this technology with their Insight and Prius models in the late 1990s. Then come plug-in hybrids, whereby some energy for the vehicle is supplied as electricity from the grid; these vehicles have still larger electric motors and batteries. General Motors was the first to mass-market a plug-in hybrid with its Volt in late 2011. More technically elegant but also more limited, with no combustion engine, is a pure battery electric vehicle. The first mass-market pure electric vehicle was the Nissan Leaf in December 2010. Perhaps the most promising, but also the most challenging, are fuel cell electric vehicles powered by hydrogen, whereby the fuel cell converts on-board hydrogen to electricity to power the electric motor. The first mass-market fuel cell vehicles are expected around 2016.

Fully electrified vehicles generate no tailpipe emissions and are very quiet. They provide the potential to achieve near zero emissions even on a full lifecycle basis—if the source of electricity and hydrogen is renewable (or fossil energy is used and the carbon is captured and sequestered).

Ten years ago, one might have characterized vehicle electrification as a disruptive technology. No longer.

Every major car company is actively pursuing these zero-emission technologies, and most have such vehicles in production, or nearly so. The challenge is to sustain the momentum. Costs of new technology are always high. That is the case here. Strong, durable policy is needed to keep automakers and consumers engaged. These policies include incentives and mandates for early production and purchase; government support of charging and hydrogen supply infrastructure; market-based policies that internalize the cost of climate change and provide an incentive to consumers and automakers for buying and selling low-carbon vehicles and fuels; and performance-based standards to provide a durable regulatory framework for automakers as they plan for the future.

SUMMARY

We need dramatic changes in how we harness and use energy. We need to improve our technologies and we need to learn new behaviors. But new technologies and new behaviors do not appear spontaneously. They take time. Unfortunately, we cannot directly and immediately observe climate change—unlike smog, polluted water, and marred landscapes. Therein lies our predicament and our leadership dilemma – how to shift to new pathways that are initially more expensive and less convenient and where the problems are not obvious. How do we shift to a path that leads to scale economies and innovations that lead in turn to a sustainable low-carbon future? And how do we do so quickly? It is an environmental challenge unlike all others. It is a pervasive and massive problem that requires sweeping changes through our economy and society.

Yet if we don't make those tough economic choices and major lifestyle changes, then we condemn our grandchildren and great-grandchildren to, at best, an environmentally compromised world, and at worst a disastrous world of rising seas, violent storms, and raging wildfires, which will lead to massive emigration, displaced agricultural and recreational industries, and economic destruction. Who has the courage to step forward and lead? We have a choice today. In 2050, they will not.

Here are 5 guidelines and lessons to guide us to a sustainable transportation future:

1. There is no one solution—no silver bullet to create a carbon-neutral transportation system. We need a portfolio of solutions. Politicians and media grasp single solutions and hype them. Unfortunately that is a disservice. We need battery electric vehicles *and* fuel cell vehicles *and* hydrogen *and* biofuels *and* better urban land-use management *and* startup companies offering new types of mobility services *and* more rational financing and pricing of roads and parking ... and much more.
2. We need to focus on desirable pathways into the future, not simplistic end-state visions. It is much harder to design near-term policies and strategies than paint ideal visions of the future.
3. Every city, country, culture, and economy is different. The mix of solutions and the details of those solutions will vary dramatically from one location to another. In rich countries, with established infrastructure and locked-in sprawl, the emphasis should be more on improving technologies (though opportunities also remain to improve land use management and reduce vehicle use). In emerging economies, much more emphasis should be put on devising and embracing an alternative paradigm to car-centric development, to create more livable and sustainable cities.
4. The scientific community needs to engage in near-term decision-making. We need to help policy makers, regulators and legislators to understand the choices and implications of their actions or inaction. Because solutions are often local, it is crucial that the scientific community of each region participate directly in

government and industry decision-making.

5. The fifth key lesson is TAKE ACTION TODAY! Let's not leave this looming disaster as our legacy, but muster the courage and our innovative spirit to find and implement solutions. We will then leave to future generations a legacy we can be proud of.



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