Commentary: Powering America with sustainable energy in the 21st century

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The United States continues to rely heavily on foreign oil and coal-based electricity for its transportation and power generation needs, respectively. The perennial lack of a national energy policy has deprived the United States of strong direction towards the development of sustainable domestic energy resources, which are abundantly available, enhance the country's energy security, and reduce its carbon footprint. Technology innovation and economies of scale in the last ten years have made wind, solar thermal, biomass, and natural gas viable and cost-competitive alternatives to highly polluting coal. Biomass and natural gas can produce base-load electricity, whereas wind and solar can address peak demand, when combined with fossils or with energy storage systems like batteries. In vehicles, biofuels and electric motors can rather seamlessly replace gasoline and reduce significantly our dependence on foreign oil. While each form of alternative energy has its own advantages, they can all contribute to economic growth in the 21st century by attracting investment, creating jobs, generating tax revenues, and making the entire US economy more sustainable.
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CURRENT STATUS

For decades America has been relying heavily on fossil sources for both its electrical power and transportation fuel needs. Cheap coal is still the predominant fuel for utility plants despite the pollution it causes. Technology advances and economies of scale have reduced significantly the cost of power generation from solar thermal and especially from wind turbines to the point where wind power can be produced at grid parity. Yet, renewable power sources still account for 5% of the US electricity.

In the transportation sector the picture is not much greener. Oil products still dominate the liquid fuel market with ethanol accounting for just around 10% (Ref. 1) and biodiesel for less than 1%.[2] Advanced biofuel technologies using domestic biomass and algae represent American innovations that are steadily advancing towards the demonstration stage. The goal is to ramp up production of such sustainable fuels over the course of the next 10 years to the tune of several billion gallons annually in order to make a dent in our oil imports.

The economic crisis of the last 4 years has resulted in lower fuel use. As a result, oil imports have dropped, but with recovery picking up steam, energy use will once again be on the rise. Unfortunately, the US never developed an energy policy or a vision of how its economy can make better use of energy conservation measures and domestic resources. In the absence of federal policies, individual States have taken their own steps regarding alternative energy from biofuel mandates in the Midwest to massive permitting for natural gas drilling in the Northeast.

Although climate change is still a subject of debate, it is becoming more widely accepted that reducing carbon emissions in business-friendly and cost-effective ways is a prudent step towards sustainable economic development. Efforts to minimize the carbon footprint should be viewed as an "insurance policy," even by those who doubt the scientific evidence of global warming. Moreover, domestic energy sources, such as biofuels and natural gas, not only reduce carbon emissions but also lessen US dependence on foreign oil for national security reasons.

As a nation we enjoy low-cost electricity and fuels because we continue to ignore the real cost of fossils, such as coal and oil, on a life-cycle basis. The pollution released from the combustion of such fuels negatively impacts human health, work productivity, and environmental quality. Unfortunately, politicians choose to ignore this reality, thus *de facto* handicapping future generations, who will inherit a largely unsustainable world.

We have alternative energy options at our disposal to help America shift its economy to a more sustainable basis, create new job opportunities, and maintain its technological superiority in the world. In this paper we review those options from the practical standpoints of innovative technology and business opportunities.

THE CASE FOR DOMESTIC SUSTAINABLE ENERGY

It is no secret that the US has never had an energy policy that articulated a long-term vision for the nation's energy future. Instead, the politicians have been resorting to measures by merely reacting to geopolitical events, such as rising oil prices or, increasingly lately, turmoil in the Middle East. In the absence of a federal policy, individual states have taken matters into their own hands by legislating actions that promote energy diversification in ways customized to the market realities of each State.

Although a State-based approach has its advantages, national coordination and harmonization would dramatically improve the overall energy landscape of the country. For example, as energy demand is expected to grow with economic expansion after the current recession, there is grave concern about the ability of the aging US grid system to accommodate increased demand and supply and to integrate seamlessly alternative sources of energy. Such crucial issues need to be addressed at the national level.

The heavy reliance on foreign oil renders the country susceptible to political pressure by rogue regimes controlling energy resources overseas. It is no secret that oil security has been a major reason for the wars the US has been fighting in the Middle East. Both lives and money have been expanded to protect overseas oil fields at a time when the country faces so many domestic challenges. Treating the symptoms (political instability overseas) without addressing the root cause (dependency on foreign energy) will not resolve our energy security concerns. Immediate action is necessary to diversify our energy portfolio for both economic and political reasons. The US is rich in domestic biomass, wind, solar, and natural gas resources, which—with political and business will—can form the bulk of our future energy resources.

Energy conservation measures in both electricity and fuel use are the obvious first and most immediately effective steps towards decreasing energy demand to save money and reduce emissions. Beyond such measures, the prospects for the two sectors—power and transportation—differ, but in both cases there are promising options that should be readily implemented.

POWER GENERATION OPTIONS

US power generation is primarily based on fossil resources. Fig. 1 shows that coal accounts for 42%, natural gas for 25%, nuclear for 19%, hydroelectric for 8%, and non-hydro renewables for a mere 5%.[3] Coal is a plentiful and cheap source of energy, so it comes as no surprise that almost half of our electricity is derived from it. However, coal combustion is known to be a heavy carbon dioxide (CO_2) emitter and a major source of air and water pollution wreaking havoc especially on communities that host coal mining or coal burning operations. The 2008 coal ash disaster at the Tennessee Valley Authority Kingston plant is a grim reminder of coal mining's catastrophic potential for humans and the environment.[4]

The power generation picture has not varied substantially over the last several decades. However, this could change quickly, thanks to the vast reserves of shale gas discovered in many parts of the country from the Rockies to Texas and the Northeast. Gas can be readily accessed through hydraulic fracturing (fracking) of shale rock. Fracking is carried out by blasting shale rock with pressurized hot water mixed with sand and chemicals. The blast creates fissures through which natural gas escapes towards the surface from several thousand feet underground.

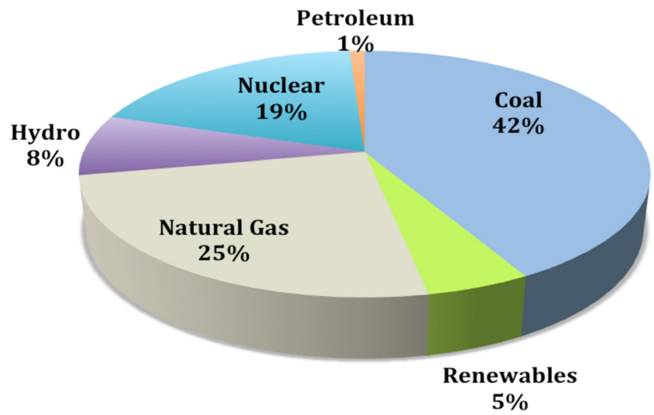

FIG. 1. US electricity generation portfolio in 2011.

In the last decade this technology has seen an explosive deployment across the country as large and small companies tap into gas reserves that were previously considered inaccessible or uneconomical. The billions of cubic feet of gas believed to lie underground have led to thousands of contracts with private landowners, who get paid royalties for allowing wells to be drilled on their property. As a result, fracking activities for gas production have increased dramatically to date.

On the positive side, natural gas is a domestic fuel with a 44% lower carbon footprint than coal per unit of power generated.[5] This benefit coupled with the abundance of gas can enable the US to gradually convert coal-fired plants to gas-fired ones, thus promoting economic growth through investment, tax revenue generation, and thousands of jobs in the gas sector. At the same time by shutting down polluting and aging coal-fired plants the country will benefit from drastically reduced carbon emissions. The ample supply of gas brought its price below $4/million Btu in 2012, thus reducing the cost of power production and making the US industry more competitive globally. Given the importance of energy security to national security, natural gas should be a key component in any US energy policy.

On the negative side, fracking appears to have major environmental consequences: scientific studies and investigative reports have documented cases of water table pollution related to fracking operations (methane detected in drinking water) and release of radioactivity to the surface from underground.[6] Moreover, soil and surface water pollution has been reported due to the often-secretive chemicals used in the fracking cocktail. As a result, some countries, like France, have banned the practice all together.[7]

Given the importance of gas to US national security, a more practical approach would be to continue fracking, but at the same time strengthen the States' regulatory authority to better safeguard environmental quality. Several States are already taking measures to regulate the industry. Even with additional costs incurred by more stringent regulation, natural gas is expected to remain cost-competitive for years to come. This is a positive development because the US needs domestic, cleaner, and affordable sources of energy, but not at the expense of a clean environment.

Following coal and natural gas, nuclear power represents 19% of the US portfolio. Nuclear plants emit no carbon and are therefore viewed by politicians and even by environmental groups as a means to curtail carbon emissions, while meeting increased power demand. However, the handling of nuclear waste and the risk of accidents always haunt the industry. The March 2011 disaster at Japan's Fukushima nuclear facility highlighted the risks of nuclear power and subdued public appetite for more nuclear reactors.

At a market penetration of 5%, non-hydro renewable energy still represents a rather small fraction of US power generation, but is growing at the fastest pace among energy sources. Wind power is predominant, followed by solar thermal and photovoltaics. In fact, wind has become one of the most cost-competitive forms of energy even in the absence of carbon credits, as Fig. 2 shows.[8] Thanks to the economies of scale provided by several MW-size turbines and large wind farms, wind power has proved that renewable energy can be competitive. The same is expected to happen with solar power in the near future as technical advances continue to increase the efficiency and reduce the cost of solar cells. These developments in combination with larger economies of scale will enable solar power to grow significantly over the next decade. Both solar and wind are domestic sources of power and emit no carbon, while at the same time providing opportunities for research and development (R&D) innovation, investment, employment, and exports.

The downside of wind and solar is of course their intermittent nature, which prevents them from serving the base-load needs of the grid. As a result, they currently address only peak demand in conjunction with natural gas at existing gas-fired plants. However, as energy storage systems, such as batteries and flywheels, become more cost-effective and scalable, solar and wind power are expected to play an increasingly important role in US power generation.

Biomass represents another low-carbon national resource. Biomass is any kind of plant material produced via photosynthesis, including wood, sugarcane bagasse, wheat straw, corn stover, and grasses. Its ubiquitous presence in various forms throughout the country makes biomass a promising component of the US energy portfolio. Although combustion of biomass for power generation releases CO_2, through nature's carbon cycle this carbon dioxide is re-absorbed from the atmosphere by plants (and algae) to photosynthetically produce more biomass, hence power from biomass is renewable. Every year the US generates significant amounts of cellulosic biomass in various forms, depending on local climate and ecology, including: agricultural residues, such as corn stover and wheat straw in the Midwest and sugarcane bagasse in the South; woody residues from forest management in the Northeast and Northwest; yard waste from residential and commercial properties in the South; grasses and energy crops throughout the country.

A US Department of Energy (DOE) and US Department of Agriculture (USDA) study estimated that annually almost a billion tons of biomass are generated in the US.[9] Innovative technologies are being developed to enhance the energy efficiency of biomass use. Gasification systems have been shown to improve the conversion of biomass to power and chemicals, while torrefaction turns green biomass to a denser energy "bio-coal," which can supplement (co-firing)

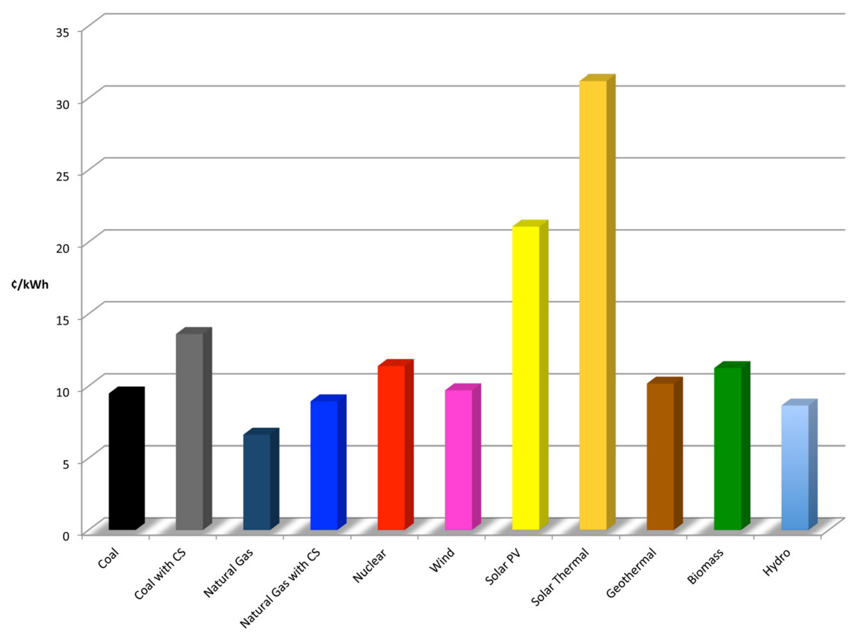

FIG. 2. Projected levelized cost of energy (national average in 2016), expressed in 2009 cents per kilowatt-hour (kWh). "CS" indicates the incorporation of carbon sequestration technologies.

or replace coal as a fuel.[10] Tapping into this abundant source of fuel can contribute significantly to our renewable power generation capacity.

Yet another plentiful renewable option is biogas energy. Liquid wastes from industrial and municipal sites are loaded with pollutants, which can serve as nutrients for microorganisms under anaerobic conditions. Hence, anaerobic digestion processes can transform polluting nutrients into biogas, a mix of methane and carbon dioxide. The methane can be readily combusted in gas turbines producing electricity and heat. Variations of the technology are already commercial, but their potential has not been exploited yet in the US. Biogas is ideally suited for industrial facilities, large farms, and municipalities, where economies of scale can lead to low-cost electricity production providing independence from the grid and reducing electric bills.

TRANSPORTATION OPTIONS

In 2010 the US consumed 138×10^9 gallons of gasoline (one gallon is approximately equal to 4 l) and 49×10^9 gallons of diesel, both derived from mainly imported oil.[11] Unlike power generation, where domestic energy sources (albeit highly polluting, such as coal) are utilized, the transportation sector depends almost 50% on oil imported from other countries, including the organization of petroleum exporting countries (OPECs), some of which are openly hostile to US interests.

The present situation makes no political or financial sense as billions of dollars are sent overseas with little benefit to US economic activity. Yet, there is no federal plan to reduce our dependence on oil, since alternatives to oil products, such as biofuels, have received attention only in the last few years. Even as renewable fuels are being developed, wasteful farm subsidies have been handed out instead of growth incentives for the renewable fuels industry.

Thanks primarily to state mandates, ethanol today represents almost 10% of the transportation fuel used in the country.[1] The 13.5×10^9 gallons of ethanol consumed in 2010 came from corn produced in Midwestern states and until recently subsidized with \$0.45 per gallon by the federal government. Moreover, a \$0.54/gal tariff imposed on imported ethanol burdened for years the import of cost-competitive sugar cane ethanol from Brazil. Historically, cane ethanol has been produced in Brazil at a lower cost than US corn ethanol and would greatly benefit American consumers, if it were imported into the country without the tariff. As a result of the corn ethanol subsidy, the American taxpayers have for years spent over $\$5 \times 10^9$ a year, the single largest agricultural subsidy, to support corn under the pretense of biofuels for energy security.

As of January 1, 2012 the corn ethanol subsidy was discontinued, but the issue may resurface again in the political arena. Cheaper sugarcane ethanol from Latin America can make a strong contribution to lowering the cost of transportation fuels for US drivers. Paradoxically, at the present time Brazil is importing ethanol from the US due to an ethanol shortage in the country related to cane sugar production. Still, this situation underlines the importance of open trade of biofuels as the only way to make renewable transportation fuels a true commodity.

Unfortunately, even the carbon footprint of corn ethanol is only marginally smaller than that of gasoline, as seen in Fig. 3.[12] This is due to the fact that corn ethanol production uses fossil sources for power generation and chemical fertilizers in the fields.[13] Hence, although corn ethanol itself is renewable, on a life-cycle basis its production results in significant carbon emissions.

In contrast to corn ethanol, sugarcane ethanol reduces by as much as 80%–90% carbon emissions compared to gasoline, since sugarcane-ethanol plants utilize their own biomass (cane fiber called bagasse) for their power needs and use vinasse, a by-product of distillation, as a natural fertilizer. Sugarcane ethanol is produced more cost-effectively than corn ethanol and, because biomass is carbon neutral, it results in a lower carbon footprint than both gasoline and corn ethanol. Technological advancements over the last 40 years in the cultivation of sugarcane and the fermentation of sugars have made Brazilian ethanol competitive with gasoline at oil prices as low as \$60 per barrel.[14]

Through the renewable fuel standard (RFS), as extended under the Energy Independence and Security Act of 2007, the US federal government has set an ambitious annual production

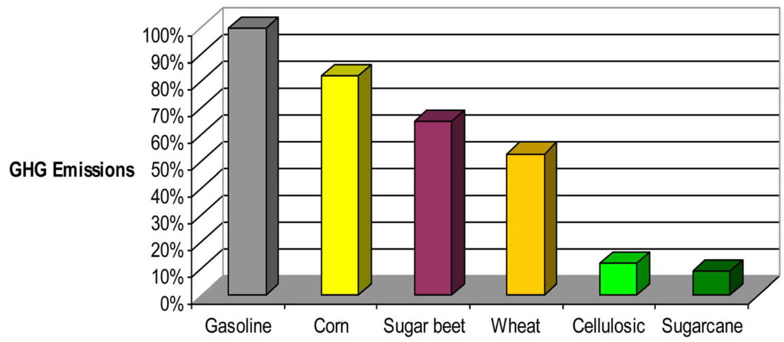

FIG. 3. Greenhouse gas (GHG) emissions when using ethanol produced from various sources compared to gasoline, as calculated on a life-cycle basis.

goal of 36×10^9 gallons of biofuels by 2022 of which only 15×10^9 gallons will be corn ethanol. As the US corn ethanol industry is approaching the 14×10^9-gallon mark, biofuels from other resources are actively being developed by a new cadre of companies investing heavily in advanced biofuels, which are derived from non-edible biomass resources (rather than corn) and algae. As a result, such biofuels do not compete with food production and are hence considered sustainable. As Fig. 3 shows, the carbon footprint of cellulosic ethanol is projected to be about 80% lower than that of gasoline. It, therefore, represents a major tool for lowering carbon emissions from our transportation sector.

ADVANCED BIOFUEL TECHNOLOGIES

The conversion of biomass to biofuels has been the subject of intense R&D work and public and private investment in the last 10 years, because there is plenty of low-cost biomass in the US. Companies, mostly funded by venture capital, have developed biochemical and thermochemical processes to convert biomass to a variety of liquid fuels, such as ethanol, butanol, and hydrocarbons. Some of those technologies are currently in the demonstration stage and expected to be soon deployed at small commercial scale. A recent technoeconomic analysis of presently available technology estimates the cost of ethanol from biomass at $3.27/gallon gasoline equivalent (in 2007 dollars) based on an annual capacity of 61×10^6 gallons of ethanol.[15]

Biochemical technologies utilize enzymes to break down biomass to sugars, which are subsequently fermented by microorganisms to biofuels. As shown in Figure 4, chemicals (at low concentrations) and cellulase enzymes are employed to reduce the cellulosic and hemicellulosic fractions of biomass, respectively, to simple sugars—mainly glucose and xylose. The sugars are subsequently fermented to ethanol, which is recovered via distillation and molecular sieves, as done in conventional ethanol operations. Lignin and other solids in the stillage can serve as fuel for power cogeneration.

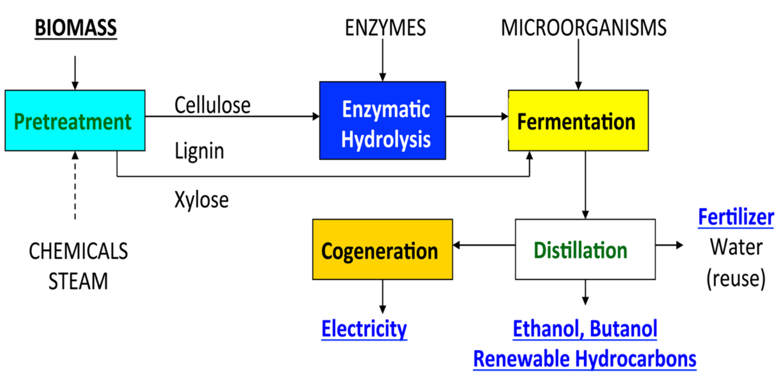

FIG. 4. Biochemical conversion of biomass to advanced biofuels.

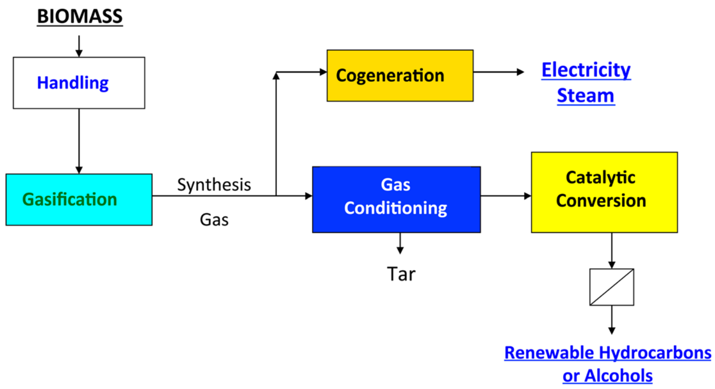

FIG. 5. Thermochemical conversion of biomass to advanced fuels.

In the thermochemical path all the organic components of biomass (cellulose, hemicellulose, and lignin) are turned into synthesis gas (syngas) via gasification, as seen in Fig. 5. The syngas is conditioned to remove tars and is subsequently converted in the presence of catalysts to alcohols or hydrocarbons depending on the type of catalysts employed.

Each technology has advantages and disadvantages. The biochemical technology involves costly cellulase enzymes and a challenging fermentation of two classes of sugars: (a) 6-carbon sugars consisting primarily of glucose derived from cellulose and (b) 5-carbon sugars consisting primarily of xylose derived from hemicellulose. Moreover, lignin cannot be utilized for ethanol (or other biofuel) production and is instead used as low-grade fuel in the boilers. On the positive side, fermentative microorganisms convert the sugars to almost exclusively ethanol.

The thermochemical technology has the advantage of using well-established coal gasification and Fischer-Tropsch (F-T) processes, although modifications are needed to adapt them to the peculiarities of biomass. Moreover, lignin is also converted to biofuel, along with cellulose and hemicellulose, adding an extra 20% or more (depending on the composition) to the biofuel yield of biomass. Challenges, on the other hand, include the use of expensive catalysts in the F-T reactions and the production of hydrocarbon or alcohol mixtures, as opposed to a single fuel, which require further separations.

In the last 5 years another promising source of alternative fuels has been aggressively developed, freshwater and saline algae. Because algae consume CO_2 to grow, algal fuels have the added benefit of contributing directly to the removal of the most prevalent greenhouse gas from the atmosphere. Algae have the advantage of growing much faster than cellulosic biomass—days instead of months. Moreover, they are cultivated in shallow ponds built on marginal land without displacing crops.

However, algae processing and production of fuels still entail engineering challenges, especially low-cost cultivation of algae, water processing, and lipid recovery, as shown in Fig. 6.

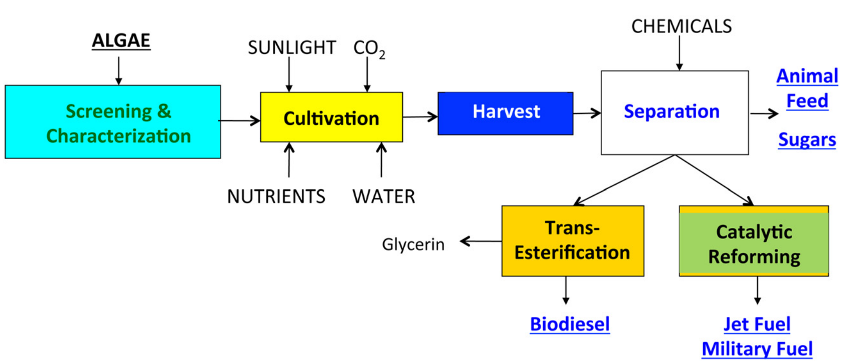

FIG. 6. Production of biofuels from algae.

Algae-derived lipids form the basis for the production of hydrocarbons for aviation and military use, as well as biodiesel for vehicles.

ELECTRIC AND ALTERNATIVE TRANSPORTATION

In addition to biofuels, there are additional options in the transportation sector to reduce dependence on oil and to lower emissions: electric vehicles and natural gas-powered vehicles. New technologies of electric vehicles have already been introduced into the marketplace, such as electric-gasoline hybrids and pure electric ones operated solely with a battery. Although an electric vehicle *per se* emits no CO_2, its contribution to a lower carbon footprint depends on how the electricity it uses is produced. Hence, the question rolls back to the power generation sector, where renewable sources and natural gas represent preferable fuel sources.

The discovery of large reserves of shale gas in the US has raised the possibility of natural gas-powered vehicles. Hence, inexpensive gas can play a dual role: generate electricity and power vehicles. The latter will obviously require modifications to existing vehicles and fuel stations, which will in turn require a significant investment. The lack of an energy policy does not help investors jump on such opportunities and hence prolongs the current status of total dependence on polluting and/or imported fuels.

Eventually, we may see truly flex fuel vehicles, able to operate on multiple fuels and blends, coming off the assembly lines of US and foreign automobile manufacturers. That is already the case in Brazil, where drivers can utilize biofuels, gasoline, blends of the two and natural gas depending on the daily price of each fuel. With an energy policy in place supporting the development of alternative and renewable fuels, the US consumers will for the first time have the choice (various fuels) and means (flex vehicles) to select domestic and cleaner fuels on a daily basis and without senseless subsidies. In addition to investors promoting renewable and alternative fuels, oil companies have started participating in clean technology ventures ranging from electric vehicles to cellulosic biofuels and algae.

CONCLUSION

Sustainable energy sources offer tremendous opportunities to advance US economic growth by investing in low-carbon innovative energy technologies, which will create private sector jobs, generate tax revenues, and place the entire economy on a more sustainable footing. In power generation, shale gas represents an immediate opportunity to displace polluting coal. Wind, solar, biomass, and biogas are plentiful natural resources that should be tapped-in cost-competitively in large scale over the next few years to support both base-load and peak electricity demand. In the transportation sector, biofuels from biomass and algae can enhance US energy security by reducing oil imports. Electric cars, in combination with cleaner electricity produced from wind, solar, biomass, and natural gas, and even natural-gas vehicles can complement alternative fuels to truly diversify the American energy portfolio.

The US government needs to develop a bipartisan roadmap towards long-term energy security by creating a level playing field for clean resources of energy. The private sector eagerly awaits such a policy to invest with confidence in the country's future. Wasteful farm subsidies and import tariffs on biofuels are counterproductive and obsolete. Instead, government support should be granted in the form of a streamlined and expedient regulatory framework and tax incentives to help the private sector commercialize new technologies and build the solar, wind, biomass, biofuels, and natural gas facilities needed to break this country's coal and oil energy dependence. Such public-private partnerships will benefit the American consumer directly and secure the country's energy future in a sustainable way.

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