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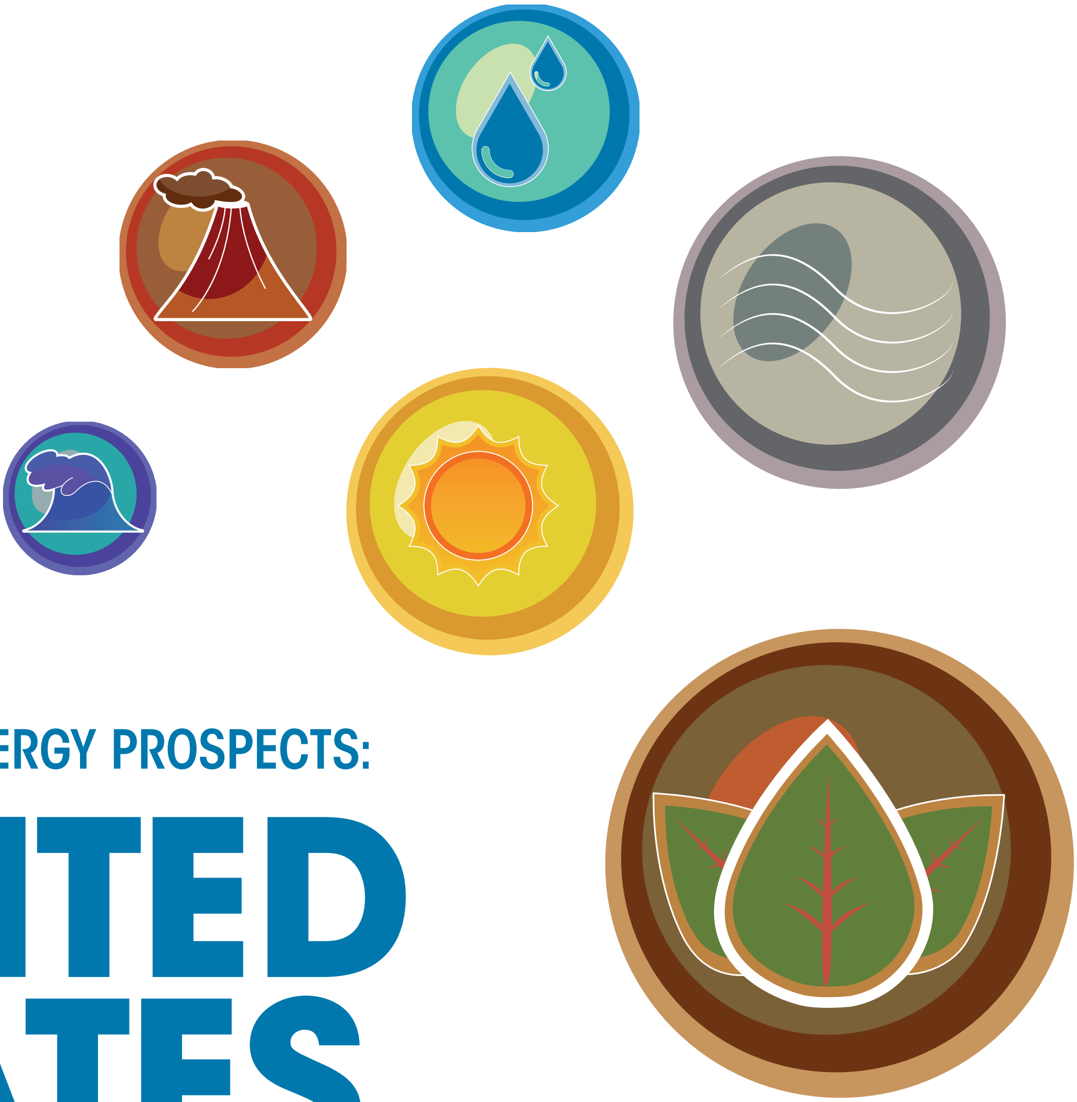
REmap 2030
A Renewable Energy Roadmap



RENEWABLE ENERGY PROSPECTS:

UNITED STATES OF AMERICA

January 2015

About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organization that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international cooperation, a center of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

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REmap 2030 analysis

January 2015

FOREWORD

REmap 2030 is IRENA's assessment of how countries can work together to double the share of renewable energy in the global energy mix by 2030. It represents an unprecedented international effort that brings together the work of more than 90 national experts in nearly 60 countries, who continue to collaborate through global webinars, regional meetings, and national workshops involving technology experts, industry bodies and policy makers. The global REmap report was released in June 2014. Following on from this global report, IRENA is releasing a series of country specific reports built on the detailed country-level analyses that are the hallmark of REmap.

REmap 2030 is both a call to action and a remarkable piece of good news. The good news is that the technology already exists to achieve the aspirational goal of doubling renewable energy in the global energy mix by 2030, and even to surpass it. Strikingly, taking external costs into account, the transition to renewables can be cost-neutral. However the call to action is this: unless countries take the necessary measures now, we will miss the goal by a considerable margin.

As the second largest energy consumer in the world the United States must play a pivotal role in meeting this goal. The US has the potential to lead a global renewable energy transition. It has some of the best wind, solar, geothermal and biomass resources, and a leading culture of innovation, entrepreneurism, and finance.

Compared to energy systems based on fossil fuel, renewable energy offers broader participation, is better for our health, creates more jobs and provides an effective route to reducing carbon emissions – a goal that becomes increasingly urgent by the day. Many renewable energy technologies already provide the most cost-effective option for delivery of energy services, with innovation and increasing deployment continuing to drive costs down.

But amid these advances, there are still misconceptions on the positive impact that renewable energy has to offer in a global drive for a sustainable and inclusive growth. Policy makers are insufficiently aware of the challenges and opportunities that lie before them, and national electorates cannot easily obtain objective and transparent information. REmap 2030 aims to contribute to remedying these shortfalls through these series of detailed, country specific reports.

REmap 2030 is an invitation to countries to forge the renewable energy future most appropriate to their circumstances, informed by the most comprehensive and transparent data available. Of course, there is no-one-size-fits-all solution. Every country is different, and each will need to take a different path. The US is blessed with some of the best renewable energy potential of any country, and REmap shows how a diverse set of renewable energy technologies can be combined to offer a secure, affordable and clean energy system.

But at its heart, REmap 2030 offers a simple choice. Take the necessary action now and build a healthy, prosperous and environmentally sustainable future through renewable energy, or carry on as usual and see our hopes for a future built on a sustainable energy system recede a long way into the future. To me, this is no choice at all. Renewable energy is not an option – it is a necessity in today's constrained climate and economically uncertain world. REmap offers a pathway to make it happen and the US has the ability to lead this transition.

Adnan Z. Amin

Director-General

International Renewable Energy Agency

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EXECUTIVE SUMMARY

HIGHLIGHTS

- REmap 2030, a global roadmap by the International Renewable Energy Agency (IRENA), looks at the realistic potential for higher renewable energy uptake in all parts of the US energy system, including power, industry, buildings, and the transport sectors. It also provides an overview of how higher shares of renewable energy can be achieved, what the technology mix would entail, and the benefits of renewable energy deployment. With such comprehensive scope, REmap fills an important knowledge gap for renewables in the US.
- The renewable energy share in the US energy mix was 7.5% in 2010 (the base year of REmap 2030 analysis). This included 2.5% renewable power, 1.6% liquid biofuels and the remaining, 3.4%, largely solid biomass used for heating in the manufacturing industry and buildings.
- Under a conservative “business as usual” case, known in this report as the Reference Case, this share will only increase to 10% by 2030. The REmap analysis shows that it is technically feasible and cost-effective to increase the renewable energy share in total final energy consumption to 27% by utilizing existing renewable energy technologies.
- Increasing the renewable energy share to 27% would save the US economy between USD 30 and USD 140 billion per year by 2030 when accounting for benefits resulting from reduced health effects and CO_2 emissions.
- Increasing the renewable energy share to 27% would require an additional investment of USD 38 billion per year in energy capacity over business as usual, resulting in total investment flows into renewable energy capacity of USD 86 billion per year.
- If the renewable energy deployment envisioned in this study was achieved the US would reduce its CO_2 emissions 30% compared to the projected 2030 level, or equivalent to a 33% reduction over the 2005 level.
- The share of renewable power would increase from around 14% today to almost 50% in REmap 2030. With the share of variable renewable power reaching 30%, the grid system would need to be enhanced with technologies and investments to strengthen transmission and interconnection.
- Significant potential for renewable energy technologies exists in the end-use sectors of transport, industry and buildings: solar thermal heat, biofuels, and electrification technologies than can utilise renewable power such as electric vehicles and heat-pumps could all see significant growth.
- Market certainty needs to be created through policy support, which must be consistent, predictable and long-term.
- Policies are particularly needed to attract investments in grid transmission and biomass logistics.
- The US needs to adopt systems that better account for the external costs of using fossil fuels, including human healthcare costs, local environmental damages, and the effect of greenhouse gas emissions and climate change on the US macroeconomy.

Leading the global transition

The United States (US) has the potential to lead the global transition to renewable energy. It has some of the best wind, solar, geothermal, hydro, and biomass resources in the world. It also has a vibrant culture of innovation, plentiful financing opportunities, and a highly skilled workforce, alongside an agile and entrepreneurial business sector.

With the right policies and support, using technologies available today, the share of renewables in the US energy mix (total final energy consumption, TFEC) could more than triple by 2030, from 7.5% in 2010 to 27%. The share of renewable energy in the power sector alone could rise to almost 50%. Renewable energy (RE) technologies can also play a much bigger role in providing fuels for the manufacturing, buildings and transport sectors.

Attaining that potential would require an investment of USD 86 billion per year between today and 2030, an incremental investment volume of USD 38 billion per year more than would have been invested into the conventional variants that are replaced. Higher shares of renewables would result in overall cost-savings to the US economy of USD 30-140 billion per year by 2030, and in net job creation, better human health, as well as reduce US carbon dioxide (CO_2) emissions by nearly one third, compared to a business as usual scenario.

REmap 2030 Country Focus

This is one of the first country reports in the REmap 2030 series from the International Renewable Energy Agency (IRENA), which explores how to double the share of renewable energy worldwide by 2030. REmap requires raising the worldwide renewable energy share from 18% today to 36% in 2030.

The US must play a major role in this transition if it is to be successful. It has the potential to become a centre of renewable energy thought and innovation, and to become the world's second largest user of renewables after China, accounting for 13% of the global use in 2030.

Without a widespread and systematic policy shift, the US risks falling far short of this potential. Under a conservative business as usual scenario (the Reference Case in this study), according to the projections of the US EIA's Annual Energy Outlook, the renewable energy share in the US energy mix will rise from around 7.5% today to only slightly above 10% by 2030. Recent proposals to limit CO_2 emissions from the power sector could increase this share, but would still be far below the potential of 27% identified in this study.

A strategy for a diverse mix of renewables

Under REmap 2030, nearly three-quarters of total US renewable energy use (across all sectors, including power generation and end-use) would come from wind and various forms of bioenergy. However a rich mix of renewable technologies is possible.

Wind: Wind offers the greatest potential for growth in US renewable power generation. The best resources primarily lie in the centre of the country (the Midwest), stretching from Texas to North Dakota. REmap 2030 would entail a fivefold increase in onshore wind capacity, from 63 gigawatt-electric (GW_e) in 2014 to 314 GW_e by 2030. It also envisages an additional 40 GW_e of capacity in offshore wind. To make this happen, the US needs to begin a large-scale investment in its transmission infrastructure.

Solar photovoltaics (PV) and concentrated solar power (CSP): Recent years have seen rapid drops in the price of solar PV technologies, as well as the launch of several landmark CSP plants. Solar resources in the US vary between regions, but across the whole lower 48 and Hawaii are higher than in Germany, the current world leader in solar PV capacity.

REmap 2030 envisages that by 2030 total installed capacity of solar PV could reach 135 GW_e, compared to 7 GW_e in 2012. This raises the prospect of a revolution in distributed generation, with over one-third of solar PV capacity installed on rooftops. Many users would also become producers, requiring reform of the grid system.

Biomass and biogas: The US can lead in modern bioenergy technologies, using its vast arable land resources, world-class potential in residues from agriculture sector, forest and mills, as well as unutilised waste and methane from landfills.

There is significant potential for biomass to be used in heating, particularly in the manufacturing industry, where its use could triple between 2010 and 2030. Biomass offers the potential for an additional 46 GW_e of power generation capacity, taking the total to 84 GW_e by 2030. About 40% of this growth would be from industrial co-generation, which also provides benefits for renewable heat generation.

Geothermal: The US has some of the world's best geothermal resources, primarily in the west, but is currently using only 10% of its potential. REmap envisages an additional 18 GW_e in power generation from geothermal, adding to 6 GW_e under current plans.

Hydro: Hydropower is currently the largest source of renewable power generation in the US, but there is limited potential for new large scale developments. Additional potential can come from retrofitting and upgrading turbines at existing dams, the addition of power generation facilities at non-powered dams, and some new run-of-river hydro projects.

Power sector: the rise of wind and solar

In REmap 2030, the share of renewable power in the US will approach 50%, led by wind, but including a diverse mix of technologies. Wind power will surpass hydropower by a factor of three to become the largest renewable power source in the US. Solar PV will see an almost 60 times growth in generation over 2010 levels.

These increases would add less than one USD cent per kWh to wholesale power generation costs. However investments must be made in grid and transmission infrastructure to account for an increasing share (up to 30%) of variable renewable power.

The importance of the buildings, transport and industry sectors in the transition

In REmap 2030, 55% of all renewable energy in the US would be in the form of non-electricity energy use, *i.e.,* bioenergy in solid, liquid or gaseous forms, or solar thermal or geothermal heat. These forms of energy are needed for heating, cooling and transport applications in the buildings, transport and industry sectors. Total use would constitute a three to four-fold increase over 2010 levels.

Heating and cooling in buildings and industry: Renewables for heating in buildings and the manufacturing industry is currently dominated by bioenergy, with around one-quarter consumed in the residential and the rest in industrial applications.

In addition to solar technologies for power generation, solar thermal technologies that harness the sun's energy for space, water and low-temperature process heat have large yet overlooked potential. In REmap 2030, solar thermal capacity could increase ten-fold over today's levels.

Geothermal energy can also be harnessed through the use of heat pumps. Including aerothermal heat pumps, REmap shows the potential for an additional 7 million heat-pump systems mainly in residential and commercial buildings by 2030.

Transport: In 2012, the US produced 13 billion gallons of biofuels which originated mainly from corn. Under REmap 2030, total biofuel production could nearly triple to 39 billion gallons – 60% of the increase would come from advanced bioethanol. Production capacity for advanced biofuels is new, and will require greater support for research and development in production processes.

However in the transport sector a shift away from fuels is underway as the economics of electric vehicles improve. Efforts in states such as California to promote zero-emission vehicles could result in a rapidly expanded market. REmap 2030 envisages a total of 27 million electric vehicles in the US car stock, compared to only 5 million under current projections. Such a shift reduces fuel use by a factor of three at least, due to the significantly higher efficiency of electric drivetrains, and increases renewable electricity production as additional power demand is assumed to be met by renewable energy sources.

The costs and benefits of REmap 2030

Increasing the renewable energy share to 27% under REmap 2030 would require a slight incremental cost for the US energy system, but would also save money when taking into account the external costs of fossil fuels.

IRENA quantifies this cost separately from the perspective of businesses and governments. The business perspective is based on national energy prices which include end-user tax and subsidies. From this perspective, REmap Options could be deployed at an average savings of USD 3.2 per megawatt-hour (MWh)

(USD 0.9 per gigajoule, GJ) compared to fossil fuels with the type of fuel being coal in the power sector, gasoline in the transport sector, and mostly natural gas for heating. From the perspective of governments, which excludes energy tax and subsidies and is therefore a better metric of understanding energy system costs, the cost would rise to USD 7.2 per MWh (USD 2.0 per GJ) – or the equivalent of paying 0.7 cents more per kWh on a typical consumer's electricity bill. This translates to a bottom line additional cost of USD 20 billion per year for the energy system as whole. When wider benefits are taken into account, such as improved human health and CO_2 emission reductions, REmap 2030 would result in net savings of USD 30-140 billion per year.

The investment need to achieve the level of renewable energy deployment in REmap 2030 would require a total investment flow of USD 86 billion per year between now and 2030 in renewable energy technologies – an increase of USD 38 billion in energy capacity investments over current projections.

Reducing CO_2 emissions

The US is currently the world's second largest emitter of CO_2, producing around 5.6 gigatonnes (Gt) of CO_2 per year, equivalent to 16% of global emissions. Given limited growth in total final energy consumption to 2030, emissions will remain flat according to the Reference Case.

REmap 2030 shows that it is possible to reduce CO_2 emissions of the US by 1.6 Gt per year in 2030, or around 30% compared to the projected 2030 level. This would be a reduction of 33% compared to 2005 levels, and consistant with the reduction goal of 26-28% by 2025 that was recently announced by the Obama Administration in the landmark climate agreement with China. Accelerated renewable energy uptake in power generation would be the main driver, accounting for over 70% of the total reduction with the remaining 30% coming from the end-use sectors.

If all REmap Options were achieved worldwide, coupled with higher energy efficiency, atmospheric CO_2 concentration would stay below 450 parts per million (ppm) of CO_2, helping to prevent average global temperatures from rising more than two degrees Celsius above pre-industrial levels.

Barriers to accelerated renewable energy growth

If renewable energy is to grow rapidly as envisioned in this report, a number of challenges need to be overcome.

Transmission: The cost of investing in transmission tends to be higher for renewable power because of distances between resource-rich areas and centres of population, the relatively smaller size of generation facilities, and the intermittent nature of some renewable sources. Building a grid for transmission and distribution that is suitable for high shares of renewable energy will take time, meaning it needs to begin now. Numerous institutional barriers stand in the way, including a lack of enforceable energy system planning, and lengthy permitting processes.

The biomass challenge: REmap 2030 envisages an increase in demand for biomass in all sectors, with demand coming close to the total available biomass supply of the US. Meeting this supply can be done sustainably; however, investments are needed to improve recovery operations and supply-chain logistics. REmap also explores an alternative case – called REmap-E – that assumes significantly lower biomass growth, and instead relies on the greater use of electricity in end-use sectors. This would include more EVs, instead of cars running on biofuels, and heat pumps.

Inertia: Transition to higher shares of renewable energy will depend on the capital stock turnover rate which varies substantially from sector to sector, from about a decade for passenger cars to more than a few decades in the manufacturing industry. Conventional energy plants in the US are reaching the end of their lifes which creates the opportunity to invest in new renewable energy capacity, but capital stock turnover relies on the relative generation costs, reliability constraints and the age profile which may result in lifetime to be extended beyond the technical limit. Stranded costs should be avoided in the transition process.

Policy needs

The making and implementing of energy policy in the US takes place at several levels: federal, state and local. This means that realising dramatic change by over-coming regulatory and economic inertia will require a concerted focus on what can be done nationwide at all government levels. The full report goes into detail about the US policy landscape and includes specific policy recommendations. In this summary these recommendations are categorised into five core areas where action can be taking to realise higher renewable energy shares.

Planning transition pathways – setting plans and developing long-term strategies to support renewable energy growth based on credible and attainable targets.

Creating an enabling business environment – in uncertain policy environments, risks related to investments increase, and hence technology costs. Policy frameworks should create appropriate conditions for investment and increase investors confidence. Additionally fossil fuel externalities should be accounted for in these policy frameworks.

Integrating renewable energy into the system – enhance the effectiveness of the electricity grid system with enabling technologies including responsive load, energy storage, hydrogen fuel cell, waste heat and smart grid technologies. Expanding transmission capacity is essential to deliver the renewable resources from remote areas to densely populated demand centers, to ensure the integration of variable energy sources and increase the transfer capacity of interconnections.

Creating and managing knowledge – the US has extensive renewable energy knowledge. However programmes to increase awareness for renewable energy and its benefits among user, installer and manufacturers should be expanded.

Unleashing innovation – A global leader in innovation, the US should continue to support innovation in new and existing technologies as well as in finance schemes to develop and deploy cost-effective and efficient renewable energy technologies. This will also ensure that high levels of renewable energy deployment will also continue after 2030 through the development and commercialization of new and breakthrough technologies.

1 INTRODUCTION

REmap 2030 is the global renewable energy roadmap of the International Renewable Energy Agency (IRENA) that shows how accelerated penetration of renewable energy in individual countries could contribute to doubling the share of renewables in the global energy mix by 2030.

Key factors in achieving this goal are biomass for heating, power generation and as biofuels, wind, solar PV and greater electrification of the energy sector. Based on the analysis of 26 countries[1], REmap 2030 suggests that existing and future renewable energy expansion, as currently planned, will result in a 21% share of renewables worldwide in 2030 (IRENA, 2014a). This leaves a 15 percentage-point gap to achieve a 36% renewable energy share in 2030 as indicated in the SE4All Global Tracking Report (The World Bank, 2013).

REmap 2030 is the result of a collaborative process between the IRENA, national REmap experts within the individual countries and other stakeholders. The current report focuses on the actual and potential role of renewable energy in the US, a major energy producer and consumer, and a major contributor of carbon dioxide (CO_2). In 2010, the US was the second largest energy consumer in the world with a total final energy consumption (TFEC) of 64 exajoules (EJ), equivalent to 19% of the global TFEC (IEA, 2013a). The US TFEC is projected to remain stable in the period between 2010 and 2030 growing by only 4% according to US Energy Information Agency's Annual Energy Outlook (AEO) (US EIA, 2013a). In the same time period, based on current policies or the Reference Case according to this study, the US share of renewable energy in the TFEC will only grow from 7.5% in 2010 to 10% in 2030, driven mostly by an increase in renewable power generation.

The US has significant potential to go beyond its Reference Case developments. According to the IRENA REmap analysis (2014a), the US could reach a total of 27% renewable energy share in TFEC by 2030 if the realizable potentials of all renewable energy technologies identified in REmap are deployed. The technology potentials to fill this gap are called the REmap Options. Given the size of the country, the relative availability of different renewable energy resources, technologies and producers, their related potential vary by region. They include geothermal, wind, solar as well as novel forms of water power (hydropower and marine hydrokinetic power). The country is also developing a wide range of transport sector technologies, such as battery electric and hybrid systems, hydrogen fuel cell, and advanced biofuels (*e.g.,* cellulosic bioethanol).

This national potential has a global importance. Figure 1 provides a breakdown of total renewable energy use among the 26 countries that have developed REmap Options as well as the contribution of the non-REmap countries. Six of these countries account for over half of the total additional renewable energy potential of the worldwide REmap Options. The US alone accounts for 19% of the identified renewable energy potential in the REmap 26 country grouping, or 13% of total world renewable energy use. Engagement of the US is essential if a global doubling goal is to be reached.

The objective of this report is to provide detailed background data and results of the US REmap country analysis, and to make suggestions how the results could be translated into action.

This report starts with a brief description of the REmap 2030 methodology (Section 2). It continues by

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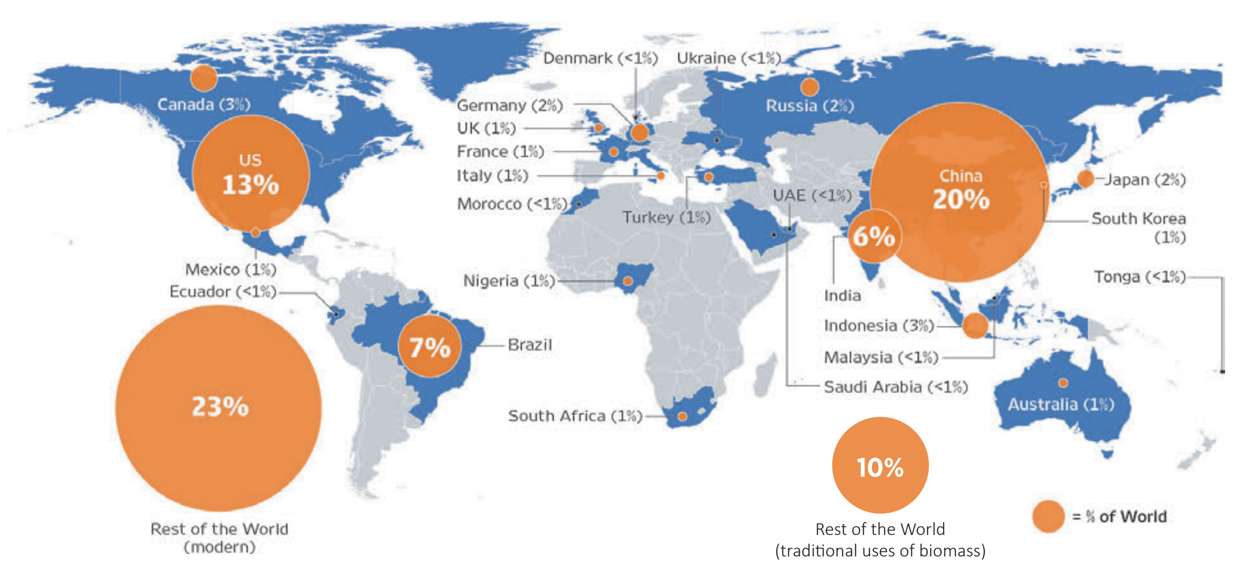
[1] The 26 countries account for three-quarters of global total final energy consumption (TFEC). TFEC includes the total combustible and non-combustible energy use from all energy carriers as fuel (for the transport sector) and to generate heat (for industry and the building sectors) as well as electricity and district heat. It excludes non-energy use, which is the use of energy carriers as feedstocks to produce chemicals and polymers. This report uses this indicator to measure the renewable energy share, consistent with the Global Tracking Framework report (The World Bank, 2013).
In this study TFEC includes the consumption of industry (including blast furnaces and coke ovens, but excluding petroleum refineries), buildings (residential and commercial) and transport sectors only. It excludes the energy use of agricultural, forestry, fishing and other small sectors which accounted for about 2% of the TFEC if it was to include these sectors as well.
The USA is a large non-energy user. Its non-energy use is about 9% of its total final consumption (TFC) which includes both the energy and non-energy use of energy carriers.

Figure 1: Contribution of the 26 REmap countries and rest of the world to total global renewable energy use in REmap 2030



Six countries (Brazil, China, India, Indonesia, Russia and the US) account for half of global potential and just two (US and China) of one-third of all potential

explaining the present energy situation and the recent trends for renewable energy use (Section 3). Section 4 provides the details of US Reference Case findings. Section 5 discusses the current policy framework at federal and state levels. Section 6 shows the renewables potential. Section 7, the heart of the report, quantifies the potentials of the REmap Options. This is followed by a discussion of the opportunities and barriers for renewable energy in the US (Section 8). Section 9 provides policy recommendations for an accelerated renewable energy uptake for the US. Although this study assumes that all renewable energy options are taken up together and by 2030, this last section also includes a discussion of energy sector and policy recommendations related to the transition period from now to 2030.

2 METHODOLOGY AND DATA SOURCES

This section explains the REmap 2030 method and summarises details about the background data used for the analysis of the US. Annexes A-F provide these background data in greater detail.

REmap is an analytical approach for assessing the gap between current national renewable energy plans, additional renewable technology options potentially available in 2030 and the the Sustainable Energy for All's (SE4All) objective of doubling the share of global renewable energy share by 2030.

REmap 2030 assesses 26 countries: Australia, Brazil, Canada, China, Denmark, Ecuador, France, Germany, India, Indonesia, Italy, Japan, Malaysia, Mexico, Morocco, Nigeria, Russia, Saudi Arabia, South Africa, South Korea, Tonga, Turkey, Ukraine, the United Arab Emirates, the United Kingdom and (in the present study) **the US**.

The analysis starts with national-level data covering both end-use (buildings, industry and transport) and the power / district heat sectors. Current national plans using 2010 as the base year of this analysis are the starting point[2]. The Reference Case represents policies in place or under consideration, including energy efficiency improvements if they are contained in these projections. The Reference Case includes the TFEC of each end-use sector and the total generation of power and district heat sectors, with a breakdown by energy carrier for the period 2010–2030. The Reference Case for the US was based on US EIA's AEO 2013.

Once the Reference Case was prepared, then additional technology options were identified. These additional technologies are defined as REmap Options. The choice of the options approach instead of a scenarios approach is deliberate: REmap 2030 is an exploratory study, not a target-setting exercise.

While the Reference Case is based on the AEO 2013, the REmap Options for the US came from a variety of sources that include:

- Renewable Electricity Futures Study (NREL, 2012a),
- Transportation Energy Futures Study (NREL, 2013),
- IRENA's Renewable energy in manufacturing roadmap (IRENA, 2014b),
- IRENA's own analysis for the buildings sector

IRENA developed a REmap tool that allows staff and external experts to input data in an energy balance for 2010, 2020 and 2030, and then assess technology options that could be deployed by 2030 consistent with an accelerated deployment of renewable energy. In addition to what is being provided in the Annexes of this report, a detailed list of these technologies and the related background data are provided online. The tool includes the cost (capital, operation and maintenance) and technical performance (reference capacity of installation, capacity factor and conversion efficiency) of renewable and conventional (fossil fuel, nuclear and traditional use of biomass) technologies for each sector analysed: industry, buildings, transport, power and district heat.

Each renewable energy technology is characterised by its costs and the cost of each REmap Option is represented by its substitution cost. Substitution costs are the difference between the annualised cost of the REmap Option and of a conventional technology used to produce the same amount of energy, divided by the total renewable energy use in final energy terms (in 2010 real US Dollar (USD) per gigajoule (GJ) of final renewable energy). This indicator provides a comparable metric for all renewable energy technologies identified in each sector.

Substitution costs are the key indicators for assessing the economic viability of REmap Options. They depend on the type of conventional technology substituted, energy prices and the characteristics of the REmap Option. The cost can be positive (incremental) or negative (savings), as many renewable energy technologies are

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[2] To the extent data availability allows, information for more recent years (e.g., 2012, 2013) were provided where relevant.

already or could be cost effective compared to conventional technologies by 2030 as a result of technological learning and economies of scale.

Based on the substitution cost and the potential of each REmap Option, country cost supply curves were developed from two perspectives for the year 2030: government and business. In the government perspective, costs exclude energy taxes and subsidies, and a standard 10% discount rate was used which allows comparison across countries. Estimating a government perspective allows for a comparison of the 26 REmap countries with each other and for a country cost-benefit analysis; the government perspective shows the cost of doubling the global renewable energy share as governments would calculate it.

For the business perspective, the process was repeated to include national prices including, for example, energy taxes, subsidies and a local cost of capital of 7% for the US in order to generate a national cost curve. This approach shows the cost of the transition as businesses and investors would calculate it. Assessment of all additional costs related to complementary infrastructure, such as transmission lines, reserve power needs, energy storage or fuel stations, are excluded from this study. However, a discussion is had on the implications of infrastructure needs on total system cost based on a review of comparable literature.

Throughout this study, renewable energy share is estimated related to TFEC. Based on TFEC, the renewable energy share can be estimated for the total of all end-use sectors of the US or for each of its end-use sectors (with and without the contribution of renewable electricity and district heat). The share of renewable power and district heat generation is also calculated.

This report also discusses the finance needs and avoided externalities related to increased renewable energy deployment. Three finance indicators are developed:

1) Net incremental system costs: This is the sum of the differences between the total capital (in USD/year) and operating expenditures (in USD/year) of all energy technologies based on their deployment in REmap 2030 and the Reference Case in the period 2010-2030 for each year.
2) Net incremental investment needs: This is the difference between the annual investment needs of all REmap Options and the investment needs of the substituted conventional technologies which would otherwise be invested in. Investment needs for renewable energy capacity are estimated for each technology by multiplying its total deployment (in gigawatt (GW)) to deliver the same energy service as conventional capacity and the investment costs (in USD per kilowatt (kW)) for the period 2010-2030. This total is then annualized by dividing the number of years covered in the analysis (i.e., 20 years between 2010 and 2030).
3) Subsidy needs: Total subsidy requirements for renewables are estimated as the difference in the delivered energy service costs for the REmap Option (in USD/GJ final energy) relative to its conventional counterpart multiplied by its deployment in a given year (in petajoules (PJ) per year).

In addition to the investment and subsidy needs, external effects related to greenhouse gas (GHG) emission reductions as well as improvements in outdoor and indoor air pollution from the decreased use of fossil fuels have been estimated.

As a first step, for each sector and energy carrier, GHG emissions from fossil fuel combustion are estimated. For this purpose, the energy content of each type of fossil fuel was multiplied by its default emission factors (based on lower heating values, LHV) as provided by the Intergovernmental Panel on Climate Change (Eggleston et al., 2006). Emissions were estimated separately for the Reference Case and REmap 2030. The difference between the two estimates yields the total net GHG emission reduction from fossil fuel combustion due to increased renewable energy use. To evaluate the related external costs related to carbon emissions, a carbon price range of USD 20-80 per tonne CO_2 is assumed (IPCC, 2007). This range was applied only to CO_2 emissions, but not other greenhouse gases. According to the IPCC (2007), carbon price should reflect the social cost of mitigating one tonne of CO_2 equivalent GHG emissions.

The external costs related to human health are estimated in a separate step, which excludes any effect related to GHG emissions. Outdoor air pollution is evaluated from the following sources: 1) outdoor emission of sulphur dioxide (SO_2), mono-nitrogen oxides (NO_x) and particulate matter of less than 2.5 micrometres ($PM_{2.5}$) from fossil fuel-based power plant operation, and 2) outdoor emissions of NO_x, and $PM_{2.5}$ from road vehicles. To evaluate the external costs related to outdoor emission of SO_2, NO_x and $PM_{2.5}$ from fossil power plant operation, the following parameters for respective pollutants were used: (a) emission factor (i.e., tonne per kWh for 2010 and 2030 taken from the IIASA GAINS database (ECRIPSE scenario (IIASA, 2014), and (b) unit external costs (i.e., Euro-per-tonne average for the European Union (EU), adapted for the US from the EU CAFE project (AEA, 2005). Values for the potential differences in external effects between the EU and the US are accounted for based on the difference in gross domestic product (GDP) values.

An extended version of the methodology of the REmap analysis can be found online at IRENA's REmap webpage[3].

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[3] www.irena.org/remap.

3 RECENT TRENDS FOR RENEWABLE ENERGY AND THE PRESENT ENERGY SITUATION

Key points

- Renewable energy share in TFEC of the US stood at 7.5% in 2010 (the base year of REmap 2030 analysis). This included 2.4% renewable power, 1.6% liquid biofuels and the remainder (3.4%) largely solid biomass in industry and building heating.
- The share renewable energy in power generation is rising in the US, from 11% in 2010 to 14% in 2013.
- Hydro accounts for more than half of renewable power generation in the US, but wind power is growing significantly. In 2013, the US had 78 gigawatt-electric (GW_e) hydro, 61 GW_e wind, 22 GW_e bioenergy, around 12 GW_e solar PV (including distributed generation) and 0.9 GW concentrated solar power (CSP) capacity installed.
- In terms of non-hydro renewable power generation the US is a leader in wind and in biomass power deployment. In contrast the US is lagging in solar PV however recent trends show an acceleration of deployment.
- The US is the largest biofuel producer in the world, accounting for 57% of world ethanol production in 2013.
- Use of solar water heaters and geothermal heat is low, in total around 100 PJ or less than 1% of total fuel demand for heating.
- There are important regional differences. Wind generation is concentrated in the Midwest. Hydro is strong in Northwest and Northeast. Biofuel production is in the Midwest. The distribution is related to varying resource endowment.

This section discusses the current energy situation of the US at the level of sector and energy carriers. It also provides a brief overview of the latest renewable energy development and capacity additions.

3.1 Recent trends for renewable energy

Power sector

Figure 2 shows the cumulative renewable energy power plant capacities as a function of the initial year the plant started operation (as of 2013). The largest renewable power generation capacity belongs to hydro plants with a total installed capacity of 79 GW_e (dark blue line). Most growth in hydro capacity took place in a period between the 1950s and the 1980s. Only few plants have been installed since the beginning of 2000s. Planned hydro capacity for next several years is between 12.1 GW_e and 16.8 GW_e (Hydropower & Dams, 2013)[4].

With significant growth in the past decade wind capacity is catching up. As of 2013, installed wind capacity has reached more than 60 GW_e. By the end of 2013 this had increased to 61 GW_e across 39 states. It represents 4% of all electricity demand (US EIA, 2013b). The weighted average age of wind plants is 4 years, lowest among all power plant technologies (US EIA, 2013b).

Besides wind, capacity for solar thermal, PV and biomass power generation technologies have also increased in the past decade (see Figure 2). By 2013, bioenergy (excluding wood) reached 5.2 GW_e and solar thermal (CSP) and PV reached 12.8 GW_e. In 2013 total installed capacity of solar PV had reached 12 GW_e, an 8 GW_e increase in just two years (US EIA, 2013a; SEIA, 2014). Solar PV is used across the US, even in states with limited solar resource (*e.g.,* the Northeast). However, it is an especially cost-effective opportunity in the Southwest (Spross, 2013). Biogas is also gaining importance. There are about 240 anaerobic digesters in farms across

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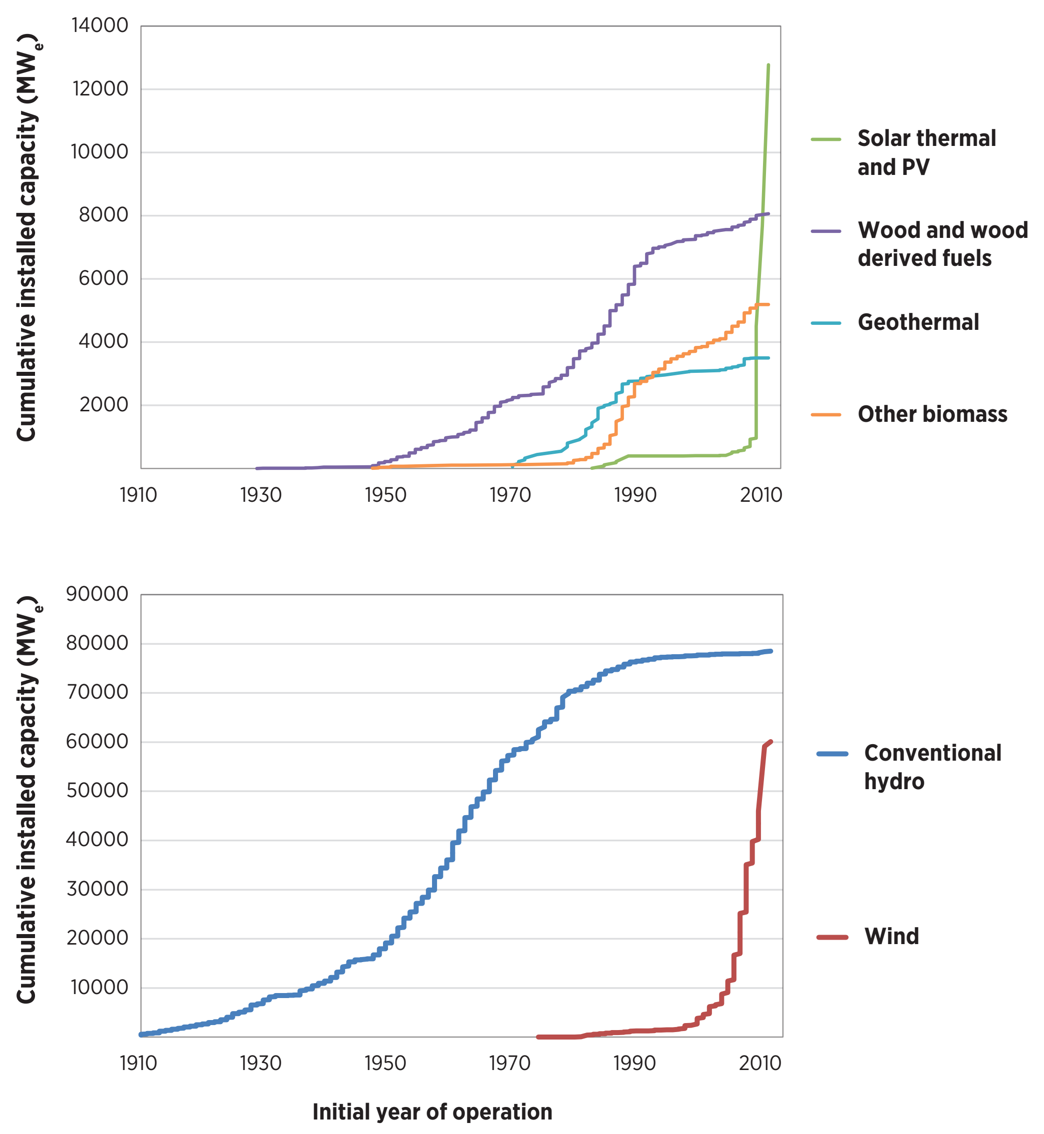
[4] A definition of "planned capacity" was not available in the original source, neither the timeline of the planned capacities.

Figure 2: Cumulative renewable power plant capacity by initial year of operation, 1910-2013



Source: US EIA (2013b)
Note: Data refers to total nameplate capacity.

the country powering about 70,000 homes. There is also a potential to raise this number by another 11,000 systems which can generate sufficient power for 3 million homes. US Environmental Protection Agency (EPA) and the US Department of Agriculture now teamed up to develop a "Biogas Opportunities Roadmap" to realise this biogas potential (Cleantechnica, 2014a).

The US has a long history of experience in CSP plants. The first plants were installed in California between 1984 and 1991. Between then and the end of 2010, CSP investments were limited. In 2010, the Solana and Ivanpah plants were added to the power system with total installed capacity of 280 megawatt-electric (MW_e) and 392 MW_e, respectively (CSP Today USA, 2014). These two plants were followed by three others (receiving conditional loan guarantees), namely Mojave, Crescent Dunes and Genesis plants. As of early 2014 installed CSP capacity in US is about 392 MW_e, however during the course of the year that number should reach more than 1 GW_e is expected to be commissioned by the end of the year (SEIA, 2014). This capacity is expected to more than double again to reach 2 GW_e in the future with the start-up of commissioned and under construction CSP plants. However, some of these projects are changing to solar PV projects as the economics of solar PV have improved.

Transport sector

In the transport sector, two main technology options are liquid biofuels and electric vehicles (EVs). In the rest of this study, it is assumed that the power demand for EVs and other modes of electric transport are powered by renewable electricity. By analogy, power demand of heat pumps in the heating sector is also assumed to be from renewables sources of electricity. A range of liquid biofuels is already deployed and, as discussed in the biomass potentials section, additional potential is possible – especially with regard to advanced biofuels and biogas.

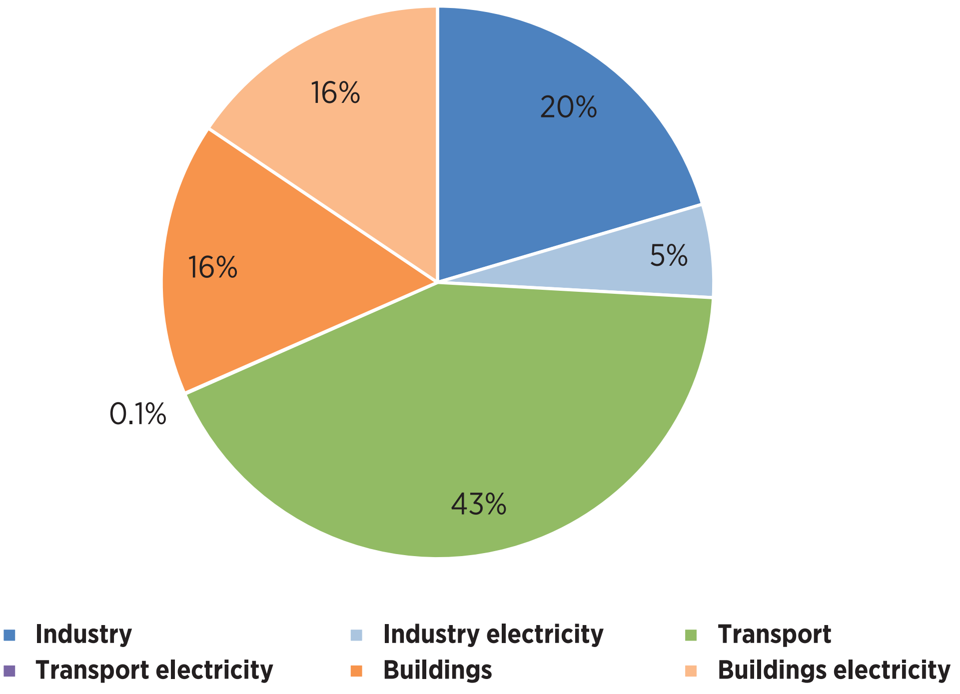
In recent years there has been an increase in the number of EVs sold in the US. In 2011 the US DoE announced a target aimed at facilitating a 1 million EVs manufacturing capacity in the US by 2015 (US DoE, 2011a). However a 2014 study (Navigant, 2014) projects the global market for battery electric vehicles (BEVs) will only reach 350,000 in 2014 and only 4% of all new passenger automobiles sold globally in 2022 will be fully electric. The economics of EVs are improving, and efforts in states such as California to promote zero-emission vehicles could result in a rapidly expanded market for electric mobility. However recent trends still show the majority of EVs sold are plug-in hybrid electric vehicles (PHEVs) and not pure battery electric (Cleantechnica, 2014b).

In addition, a shift in transport modes, such as the use of high-speed trains with renewable power instead of diesel-based trucks, or city trams for passenger cars, are other options for the transport sector.

Other end-use sectors

In buildings and the manufacturing industry, conventional fuels used to generate space and water heating, cooking and process heating can be replace by a range of technologies. These are solar thermal, geothermal

Figure 3: US TFEC breakdown, 2010



Source: IRENA analysis of US EIA (2013a) and biomass-based heat. All of these technologies are already deployed in the US and have significant further potential.

3.2 Base year renewable energy situation

Sector-level breakdown

In 2010, the US consumed 93 EJ of total primary energy (excluding non-energy use of around 7 EJ) (US EIA, 2012a). In final energy terms, US total energy demand in 2010 was 64 EJ of which 43% was consumed in transportation, 32% in the buildings sector and 25% in the industrial sector (see Figure 3)[5] (US EIA, 2013a). Electricity accounted for 21% of the TFEC of which 75% was consumed in the buildings sector, with the remainder used by industry.

Renewable energy accounted for 7.5% of TFEC in 2010. Renewable energy, when excluding electricity consumption, amounted to 10.7% in the industry sector, 6.1% in the building sector, and 4.1% in the transport sector[6]. In power generation 11.4% of electricity was renewable.

Renewable energy in TFEC share stood at 7.5% in 2010. This included 2.4% renewable power, 1.6% liquid biofuels and the remainder of 3.4% largely solid biomass in industry and building heating

The transportation sector is the largest energy user in the US. Approximately 87% of the transport sector's energy use is related to road transport. Domestic aviation accounts for another 8%. The total share of rail transport, pipeline transport and navigation accounted for in total 5% of the transport sector's TFEC (IEA, 2013a).

Energy use in the transport sector is followed by energy use of buildings (split about evenly between residential and commercial) (IEA, 2013a).

Industry sector accounted for a quarter of the US TFEC in 2010. The chemical and petrochemical sector (excluding its non-energy use) was the largest industrial energy user accounting for 25% of the US total final industrial energy consumption. Other large industrial energy uses are the pulp and paper (18%), food and tobacco (11%), iron and steel (10%) and the non-metallic minerals (9%) sectors (IEA, 2013a).

The breakdown of TFEC at a sector level has somewhat changed in the past three decades for the industry and transport sectors. The share of industrial energy use was between 30% and 35% in the 1980s whereas today it is about 25%. In comparison, the share of the transport sector has increased from about 35-40% to about 45% in the same period. The share of the building sector has remained relatively unchanged. The change in breakdown of sector level energy use in the US was mainly due to the increasing demand from the transport sector and the slowly decreasing industrial energy use in the period between 1980 and 2010 (IEA, 2013a).

In 2010, hydroelectricity made up 55% of renewable electricity generation, followed by wind with 20%, biomass 16%, biogas 4%, geothermal 3% and solar PV/CSP with just above 1% (Figure 4). However in the 3 years since then there has been a large expansion of wind and solar generation capacity. By 2012, a total of 86 GW_e of non-hydro renewables capacity had been installed. This is an increase of 29 GW_e since 2010 which has resulted in an increase in the renewable share in power generation to 12.2% in 2012 (REN21, 2013). Recent reports have also indicated that renewable power could reach 14% of total electricity production in 2013 (US EIA, 2013a).

Hydro accounts for more than half of renewable power generation but especially wind power generation is growing. By the end of 2013 the US had 79 GW_e hydro, 61 GW_e wind, 13 GW_e bioenergy and around 13 GW_e solar capacity installed

Fossil and nuclear energy play a very important role in the electricity supply of the US and in recent years domestic natural gas output has increased significantly.

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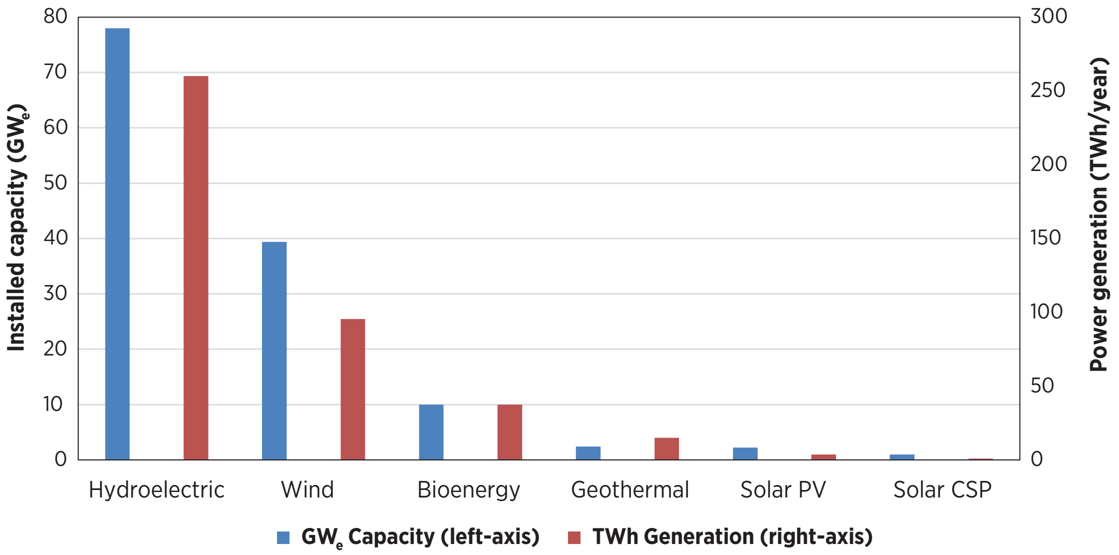
[5] Primary energy consumption refers to the direct use or supply of all energy carriers (*e.g.,* crude oil) without being converted or transformed to another form of energy (*e.g.,* heat). It is therefore higher than TFEC which only looks at the consumption of energy carriers such as fuels for transport sector or heating applications or electricity for appliances (see footnote 1).

[6] Providing the renewable energy share excluding power demand provides the contribution of renewable technologies in the sector's total fuel use only. This is important to know to exclude the effect of renewable power which is often outside the boundaries of end-use sectors.

Figure 4: Renewable power capacity and generation, 2010



Source: US EIA (2013a)

Even though the US coal supply is one of the largest in the world, its use in power generation has declined in recent years (though in 2013 this trend has reversed slightly). This is due in part to lower than projected energy demand, but also because of increased use of natural gas and renewables in the power sector. However despite the increases in renewables, fossil fuel and nuclear-based generation still accounted for 89% of production in 2010.

In the end-use sectors, biomass as a source of heating in buildings and industry and as fuel for transport made up the majority of renewable energy consumed in 2010. When excluding electricity consumption, biomass made up 10% of consumed energy in industry, and 4.1% as biofuels in the transport sector. In buildings biomass amounted to 5% of non-electricity energy supply with a small solar thermal contribution of 0.3%. In industry and buildings there is also a very small contribution of geothermal based heat.

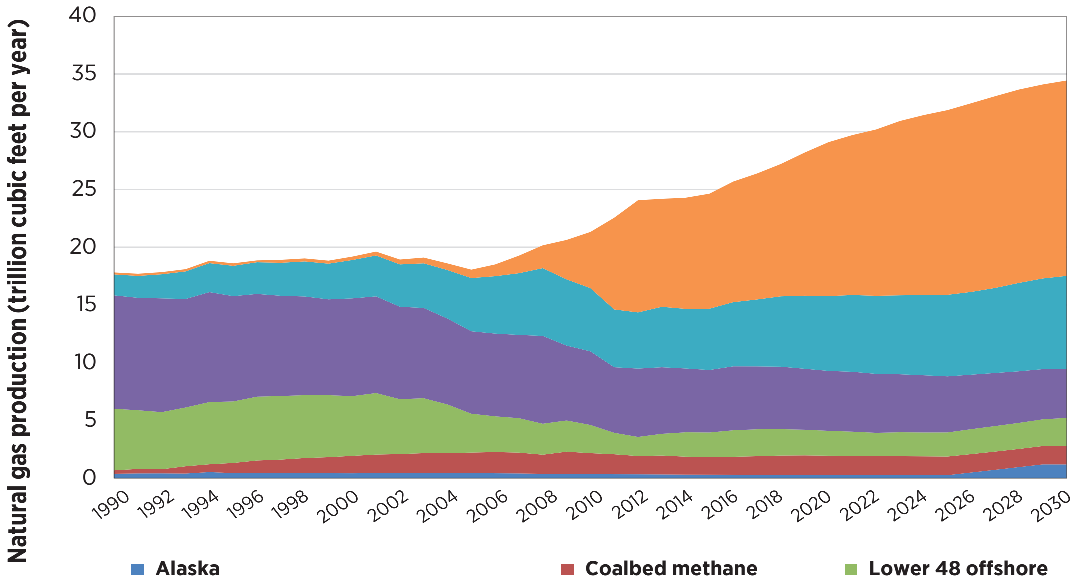
Fossil fuels dominate in end-use sectors as a source of heat production or transport fuel. In industry natural gas provides 55% of consumed energy, coal 10%, and oil products 24%. In buildings, natural gas provides 76% of consumed energy with fuel oil use amounting to 17%. In transport, petroleum-based fuels are even more dominant, accounting for 96% of the sector's total fuel use.

Three quarters of the total US electricity demand was consumed in the building sector. Almost 30% is consumed for lighting, around 25% by appliances, around 25% for space cooling and refrigeration, and the remainder is for other uses such as water heating, ventilation, etc. Electricity consumption in the industry sector was largely related to the chemical and petrochemicals, paper pulp and printing, and metals industry. Half of total consumption is for motor drives, followed by process heating (12%), heating, ventilation and air-conditioning (HVAC), refrigeration and cooling, electrochemical processes and lighting (each accounting for about 8% of the total demand) (US EIA, 2013c). Transport sectors takes a negligible fraction of US's total electricity demand, less than 1%, used largely for rail and tram lines. There is significant potential to increase electricity use, particularly in transport with railway electrification and electric passenger transport.

Conventional fuel markets

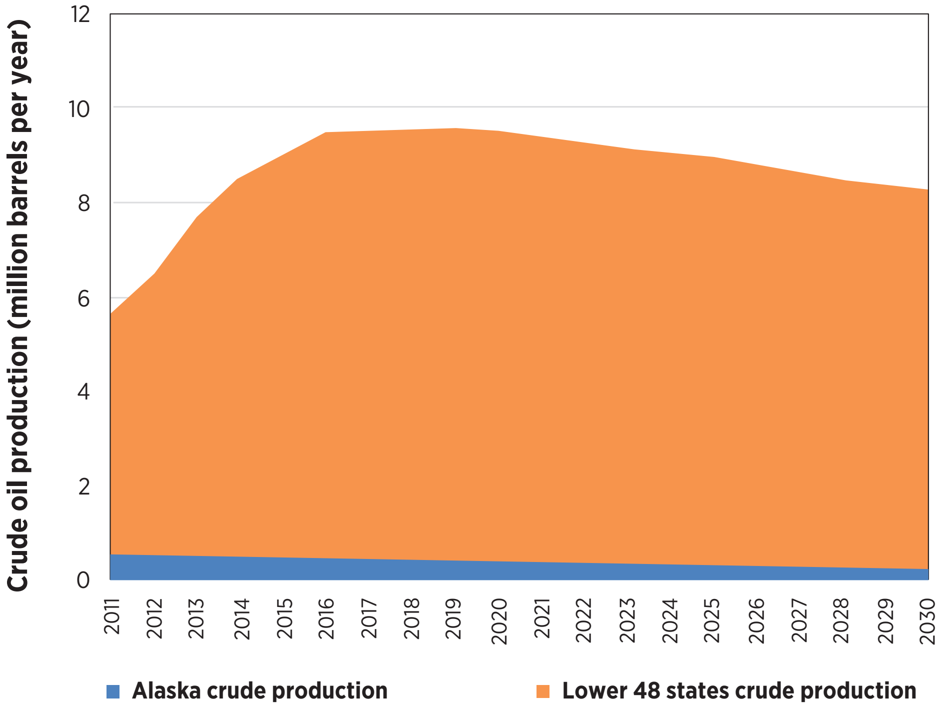
The US is a large producer of fossil fuels. In 2010, production of coal and coal products, natural gas and crude oil reached 22.3 EJ, 20.7 EJ and 14.5 EJ, respectively. US natural gas production accounted for 18% of global output in 2010. Figure 5 shows the historical developments in the US natural gas production between 1990 and 2012, as well as projections to 2030. Shale gas was

Figure 5: US natural gas production, historical developments and projections, 1990-2030



Source: US EIA (2014b)

Figure 6: US crude oil production projection to 2030



Source: US EIA (2014b)

around 20% of total US natural gas production in 2010 (US EIA, 2014a); by 2013, it accounted half of total output (see Box 1).

Total crude oil supply in 2012 reached 15 million barrels per day (mbd), 1.3% higher than the year before. Nearly 40% of the total supply was own production (6.5 mbd) with the remainder being imports (8.4 mbd). Production in Gulf Coast, Southwest and the Gulf of Mexico accounted for nearly half of the total (US EIA, 2014c). Production is projected to peak by 2015 slightly above 9.6 mbd and decline onwards to approximately 8 mbd

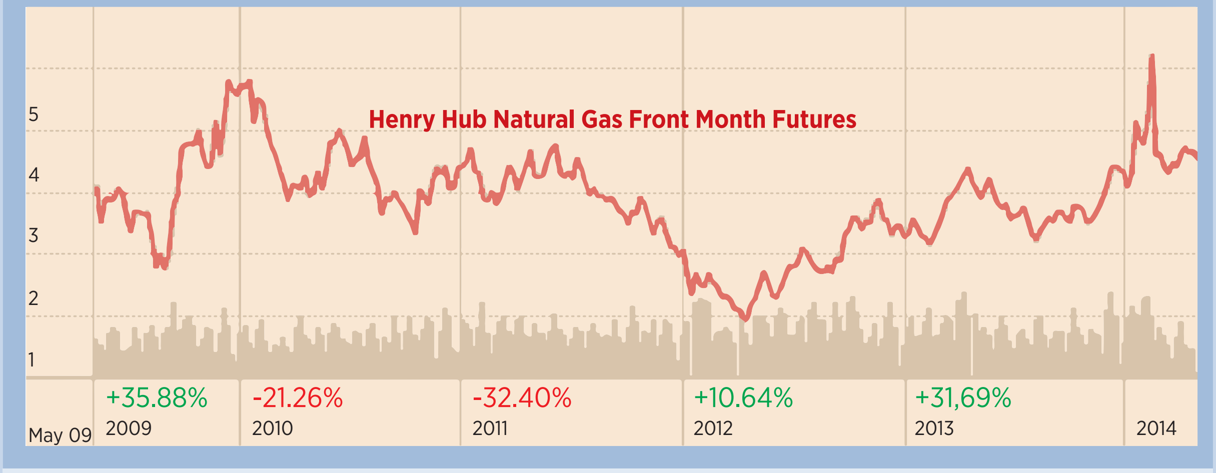
Box 1: The emergence of shale gas and its impact on the energy sector

US natural gas production stood at 24.3 trillion cubic feet (tcf; dry gas) in 2013 (US EIA, 2014a). Shale gas production stood at 10.3 tcf in 2012 and reached half of total gas production in 2013. Total shale gas volume grew eightfold between 2007 and 2012. The EIA projects a continued growth of US shale gas production, and total gas production is projected to reach 37.6 tcf in 2040 (US EIA, 2014b). The US overtook Russia as the largest gas producer in the world in 2013.

US gas prices hit a low early 2012, around USD 2 per GJ (USD 2.1 per million British thermal units, MBtu). They have steadily risen since, to a level of around USD 4.5 per GJ. Various studies indicate that USD 4.5-6 per GJ is a realistic estimate for shale gas production cost (Mearns, 2013). Production costs for shale gas are considerably higher than for conventional gas. This sets a bottom for gas prices. Renewables in the US have to compete at these prices.

Some differences exist on a state level due to variable transportation distance. Natural gas prices for power generation stood in 2013 at USD 4.5 in California, USD 5.0 in Florida, USD 5.3 in New York, USD 3.9 in Texas per GJ (US EIA, 2014b). Transportation can add up to USD 1 per GJ.

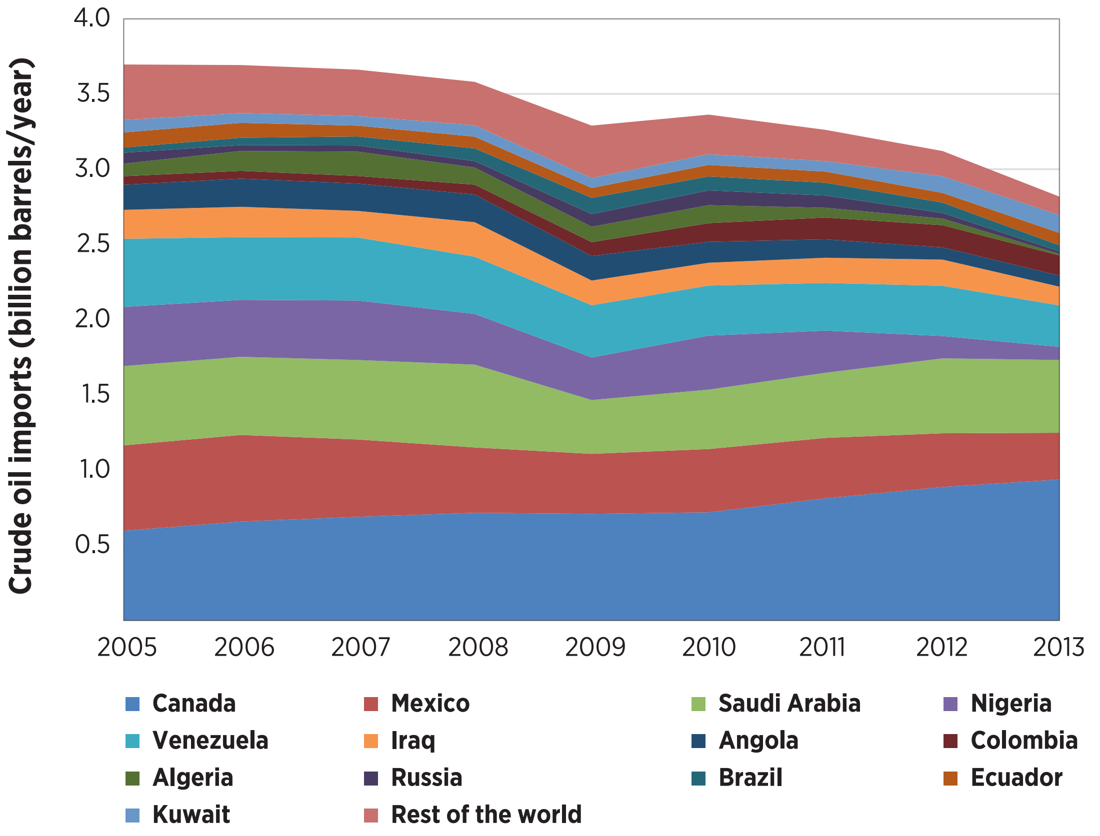
Figure 7: US Henry Hub gas prices May 2009-May 2014



Source: FT (2014)

While shale gas today offers a cost-effective alternative to some other energy sources, there are risks around relying heavily on shale gas. Based on today's investment decisions, power plants and manufacturing facilities will run on natural gas for the next 40 to 50 years. If there are changes in prices, this will affect the competitiveness of these plants, especially export-driven chemicals production. Although natural gas is priced locally and, unlike oil, not globally, if it starts receiving a global price with massive liquefied natural gas (LNG) exports, consumers will be more vulnerable to price shocks. In the transition to a less emission intensive energy system, gas may play a key role, but since it is still a fossil fuel, it emits CO_2. Hence it can only contribute to a limited extent to realize substantial emission reductions in the long-term.

Figure 8: Breakdown of US crude oil imports by country, 2005-2013



Source: US EIA (2014b)

by 2030. Production is projected to rise further in particular in the Gulf Coast and Southwest in the short-term (US EIA 2014c). Projections of the US EIA (2014b) show that total supply will remain at today's levels. This indicates that crude oil imports will increase after 2020 as production declines.

US coal production is about 15% of the total global production (IEA, 2013a). The US exports about 10% of its total coal production. The exports of natural gas are about 5% of the total produced (US EIA, 2014b). In comparison, more than 60% and 16% of US crude oil and natural gas consumption is imported, respectively.

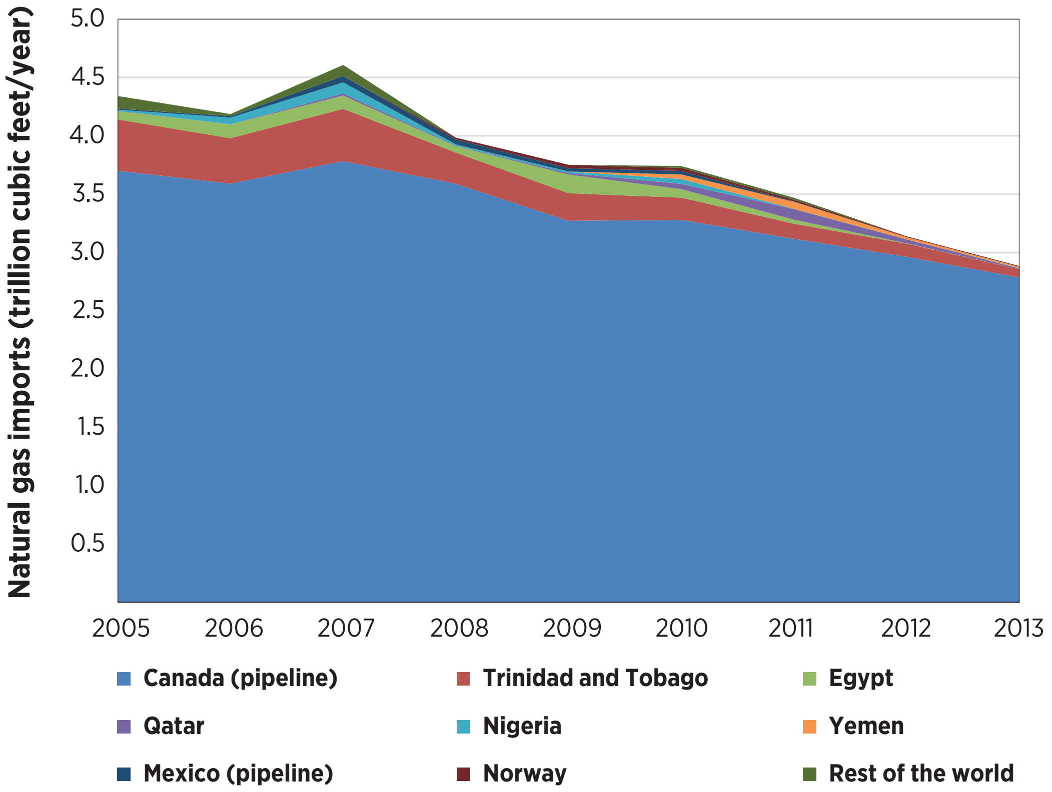
Total crude oil imports are declining. Total imports in 2013 were about 24% lower than the volume in 2005, implying an annual decline of 3.3%. In 2013, one-third of the total US crude oil imports came from Canada, 17% from Saudi Arabia, 11% from Mexico and 3% from Nigeria (see Figure 8). Together these four countries accounted for two-thirds of the total US crude oil imports in 2013.

As with crude oil, natural gas imports are also declining, and even at an even faster rate of 5% per year. Compared to 2005, total natural gas imports were one-third lower in 2013. Approximately 90% of the total natural gas imports come from Canada (via pipeline) (see Figure 9). This is followed by the imports from Trinidad and Tobago and Middle Eastern and African countries.

Exports and imports of electricity accounted for less than 1% of total production; imports amounted to 45 TWh/year and exports stood at 19 TWh/year in 2010 (US EIA, 2014b). This is mostly attributed to hydropower imports in the Northeast from Quebec, Canada.

Figure 10 shows the total primary energy supply for fossil fuels and nuclear between 2010 and 2030 based

Figure 9: Breakdown of US natural gas imports by country, 2005-2013



Source: US EIA (2014b)

on the projections of the US EIA (2014b). Supply of fossil fuels is projected to remain same in the entire period with minor changes in the fuel mix. There is a slight shift from crude oil products to natural gas. Natural gas is projected to account for a large share of the total power generation fuel mix with its demand increasing by about 13% in the 2010-2030 period. In comparison, oil demand will decrease by 8% in the transport sector which accounts for more than 80% of its supply.

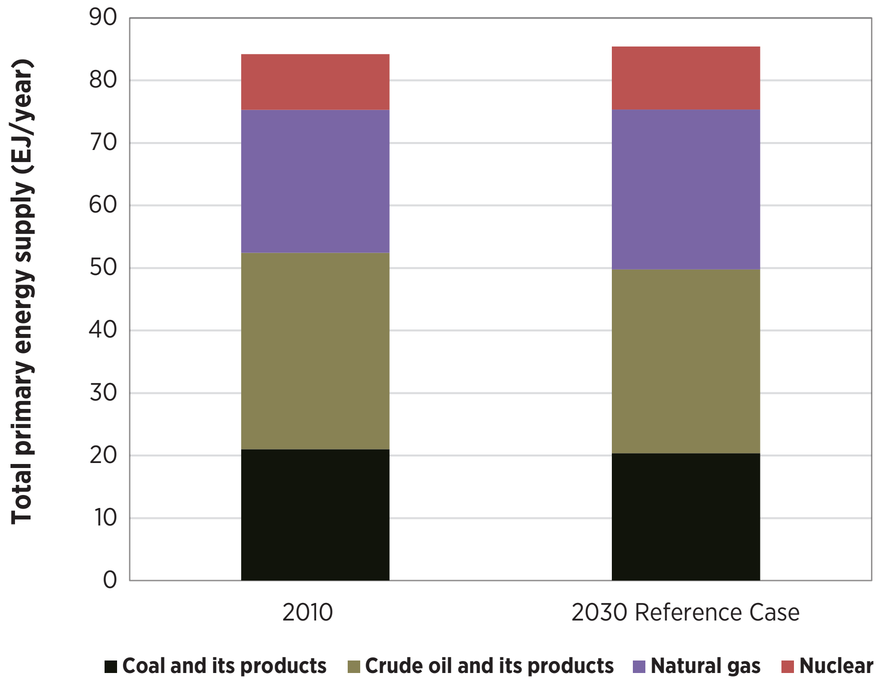
Looking forward, the EIA in its AEO 2012 projects relatively modest price growth for coal from USD 2.5 in 2010 to USD 3 per GJ in 2030 (delivered), and for natural gas from USD 4.1 to USD 6.6 per GJ over the same time period. The result is that the average electricity price is projected to increase from USD 11 to USD 12 cents per kWh in the same period. The price for natural gas for households will rise from USD 11.7 to USD 14 per GJ and for industry from USD 5.8 to USD 6.9 per GJ.

More information on the assumed energy prices to 2030 for the US REmap analysis can be found in Annex A.

Renewable energy markets in end-use sectors

When excluding electricity, the importance of bioenergy become evident in the end-use sectors. Being the second largest bioenergy consumer worldwide (first in the transportation sector) following Brazil, the US is also one of the largest producers of various bioenergy commodities. In 2011, its wood pellet production reached 4.7 megatonnes (Mt) (equivalent to 80 PJ) which is a quarter of the global production (Vakkilainen, Kuparinen and Heinimoe, 2013). Although production declined during the 2008-2009 economic recession, investments from European investors continue to increase, largely due to increasing domestic demand, but also for export (Goh *et al.*, 2013). Three US pellet mills are among the top-10 largest in the world, one in Waycross, Georgia (800 kilotonnes (kt) per year), another in Cottondale,

Figure 10: Total primary energy supply of conventional energy carriers, 2010-2030



Source: IRENA analysis based on US EIA (2014b)

Florida (550 kt/year) and one other in Hertford, North Carolina (400 kt/year) (Vakkilainen, Kuparinen and Heinimoe, 2013). Recent trends show new investments mainly in wood processing mills (mainly in the South-eastern US), partly due to decreasing production of pulp and paper, but also because logistic infrastructure is well established and feedstock is competitive.

The US is also the largest fuel ethanol producer worldwide. In 2013, it accounted for about 57% of the total global production with a total production of 50.3 billion litres per year (13.3 billion gallons) (RFA, 2014). 14 of the top-15 largest ethanol mills[7] are located in the US with capacities ranging between 0.4 and 1.1 billion litres (0.11-0.30 billion gallons) per year per mill (Vakkilainen, Kuparinen and Heinimoe, 2013). The US is also the second largest producer of biodiesel, following the total production of all EU countries. In 2013, the US accounted for 16% of the total global biodiesel production with an output of 4.4 billion litres (1.16 billion gallons) per year (F.O. Licht, 2013). The US has a number of large biodiesel plants, though they are smaller in size than the plants in Europe. Four of the largest plants in the US have a total annual production capacity of 1.4 billion litres (0.37 billion gallons) per year (Vakkilainen, Kuparinen and Heinimoe, 2013).

The US is the largest fuel ethanol producer in the world, accounting for 57% of world ethanol production in 2013

Through regulations, EPA ensures that a share of the transportation fuels sold in the US consists of renewables. EPA developed and implemented the Renewable Fuel Standard (RFS) program via collaboration with refiners, renewable fuel producers, and other stakeholders. The first phase of the program (RFS1) aimed to reach a blending of 7.5 billion gallons of renewable fuel in gasoline by 2012.

The RFS program was expanded to RFS2 to include diesel next to gasoline, and total blended renewable fuel from 9 billion gallons in 2008 to 36 billion gallons

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[7] Mills are typically called as biorefineries.

by 2022. There is also a lifecycle GHG performance threshold to ensure that renewable fuels emit less GHG relative to the conventional fuels. RFS2 originally mandated 100 million gallons (equivalent 378 million litres) of cellulosic biofuel in 2010; however, the EPA adjusted this down to 5 million gallons (18.9 million litres) when it became clear that the original volume would not be met. Even the 5 million mandate proved much higher than actual production. There are also a number of arguments from consumers groups about higher blending rates for ethanol such as compatibility with older cars, and small engine wear.

Up until a few years ago the US federal government expected advanced ethanol technology would come from cellulosic processing methods utilizing enzymatic hydrolysis to be the dominant source of new biofuels, however by 2014 a diversity of approaches for the production of cellulosic biofuels have started to be deployed.

In 2013 the first commercial-scale cellulosic biofuel facilities in the US began full operations, achieving 814 million liters of annual production on a gasoline equivalent basis by 2014 (215 million gallons/year). In 2013, total cellulosic ethanol production capacity in the US reached 46 million litres per year (12 million gallons/year) (Janssen *et al.*, 2013). The cellulosic biofuel mandate of the RFS2 (the unrevised mandate requires 250 million gallons per year of production by 2011) will be therefore met more than three years behind schedule. There are currently 9 advanced ethanol plants operating, with a total capacity of 25 million litres (6.6 million gallons) per year (Janssen *et al.*, 2013). However advanced biofuel plant production capacity is increasing, and there are many other plants under construction, including 12 commercial-scale cellulosic ethanol, butanol and isobutanol plants with production capacities ranging between 15 and 110 million litres (4-29 million gallons) per year. Some of these plants have already started production in 2013, and some others will start this year (Sheridan, 2013). Feedstocks for these plants vary, and they include corn residues, wheat straw or grain sorghum. These facilities will employ six different pathways, with three pathways producing hydrocarbon-based biofuels (catalytic pyrolysis and hydrotreating; gasification and Fischer-Tropsch synthesis; and gasification and methanol-to-gasoline) and three producing cellulosic ethanol (dilute acid hydrolysis, fermentation to acetic acid, and chemical synthesis; enzymatic hydrolysis; and consolidated bioprocessing). Fifty-two percent of the expected capacity in 2014 will yield hydrocarbon-based biofuels and 48% will yield cellulosic ethanol. The success or failure of these initial facilities will affect both the future composition of the cellulosic biofuels industry and the future direction of the US alternative fuels policy (Brown and Brown, 2013).

Production cost estimates of cellulosic ethanol for 2014 are about USD 2.55 per gallon based on corn stover[8] feedstock with a price of USD 60 per tonne, which is not yet competitive with bagasse-based cellulosic ethanol production costs of between USD 1.46 and 2.06 per gallon (USD 10-40 per tonne baggase). In addition, the profit margins per tonne of feedstock are negative, compared to positive margins in Brazil (Boyle, 2013).

There are also a number of algae-based demonstration plants. Moreover a “green crude oil” plant with a total capacity of 200 million litres (53 million gallons) is planned to begin production by 2018. The final product can be converted to for example jet fuel, among other fuels (Janssen *et al.*, 2013).

The US plays an important role in the international bioenergy trade. 20% of its total wood pellet production was exported to Europe in 2010 (Goh *et al.*, 2013). Regarding bioethanol, domestic production of conventional type bioethanol from corn will be more than sufficient to meet the currently effective RFS2 target of 15 billion gallons by 2022 (Lamers *et al.*, 2011). Combined with competitive production costs, this resulted in an increase in bioethanol exports, mainly to Canada and the EU.

For heating in buildings and industry, different types of renewable energy sources satisfy heating demand. In industry (excluding power and district heat generation), bioenergy provides 99.7% of total renewable energy use. In total, 1.4 EJ of renewable energy was used in 2010 for process heat generation. Most biomass is combusted in industrial co-generation plants to produce both process heat and electricity. Co-generation plants are located in various sectors such as food production (mix of waste and biogas as fuel), chemicals production (wood pellets, other residues) or wood processing (wood waste as fuel). Recovery boilers are another type

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[8] Stover consists of leaves, stalks and other residues left in the field after harvest.

of bioenergy combustion technology employed in the industry sector. In 2010, the US produced 25 Mt/year of bleached sulphate pulp and about 43 Mt/year of chemical wood pulp. Total black liquor consumption in the pulp and paper sector was about 1 EJ/year accounting for about one-third of the total global black liquor use (IEA, 2007; FAOSTAT, 2014).

Solar thermal technology is also used for generating industrial process heat. By end of 2011, total installed solar thermal capacity in the US had reached 15.9 gigawatt-thermal (GW_{th}), mostly unglazed collectors (14 GW_{th}). In addition there are 1.7 GW_{th} flat plate and 0.1 GW_{th} of evacuated tube collectors. The total of air collectors is 0.1 GW_{th}, equally shared between unglazed and glazed (AEE-Intec, 2013). Of the total glazed solar thermal capacity in US (1.9 GW_{th}) 3% is capacity related to purposes other than hot water production in houses, such as solar district heating, solar process heat and solar cooling (AEE-Intec, 2013). One of the first large-scale systems was installed in the US in California at a plant producing food products to generate steam at 250 °C (5,068 m^2 area, 2.4 megawatt-thermal (MW_{th}) capacity from a total of 384 collectors) (Sun & Wind Energy 2009; AEA, 2010; Deutsche CSP, 2013). Geothermal use provides only 0.04% of the sector's total fuel demand for process heat generation (IEA, 2013a).

Use of solar water heaters and geothermal heat is low, in total around 100 PJ or less than 1.5% of TFEC

Half of all energy use in the buildings sector is electricity. Excluding electricity use, 6.5% of all fuels used for heating and cooking are renewables. In 2010, total renewable energy use in the building sector of the US has reached 0.6 EJ/year. More than 80% of the total renewable energy demand of the buildings was in the residential sector with the remainder being in the commercial sector. About 90% of the total renewable energy use was related to bioenergy (0.5 EJ/year). Total solar thermal heat use was about 60 PJ/year. Total installed solar thermal capacity in the buildings sector was more than 15 GW_{th} by end of 2011. Geothermal heat use was about 5 PJ/year in 2010 (IEA, 2013a).

Co-generation plays an important role in the generation of power and heat in the US. As of the end of 2011, total installed co-generation capacity was 70 GW_e. About 43 GW_e of the total co-generation capacity is part of the power sector. Another 25 GW_e is industrial cogeneration. The total capacity utilisation rate in 2011 was about 57% (US EIA, 2012b).

In 2010, total power and heat production from main activity CHP plants reached 610 PJ/year (170 TWh/year) and 508 PJ/year, respectively. Total fuel demand to generate this total was 1,670 PJ/year, of which some 5-6% (about 98 PJ/year) was bioenergy. Total fuel utilisation efficiency of the main activity co-generation plants in 2010 was about 67% (IEA, 2013a). In addition, there are autoproducer co-generation plants[9]. In the case of the US, such plants generated power only. In 2010, total CHP power production reached 540 PJ/year (150 TWh/year). More than half of the total fuel input is natural gas, and another 20% is from biomass. Power generation from CHP plants accounted for approximately 7% of the total power generation in US of more than 4,000 TWh/year.

Regional differences

There are important regional differences in the US. The Midwest has extensive agricultural land and a strong manufacturing sector. It accounts for one-third of the total wind power capacity in the country as well as 80% of the country's total biofuel production capacity (ACORE, 2014a). The Northeast region is the second in terms of the total solar and biomass power capacities (ACORE, 2014a). Together with Northwest they account for a large share of the total hydro capacity. Although the sources for renewable energy in the Southeastern region are high, deployment of renewable energy has been slow because of the limited incentives for developers and investors (ACORE, 2014a). The political environment in the Southeastern region of the US has been traditionally more supportive of fossil fuels, and the wind resource availability is rather limited in the region compared to other states. However, the region is rich in solar radiation and years to come will show whether the interest to renewables will change. The western states are leaders of the country in terms of renewable energy deployment (ACORE, 2014a).

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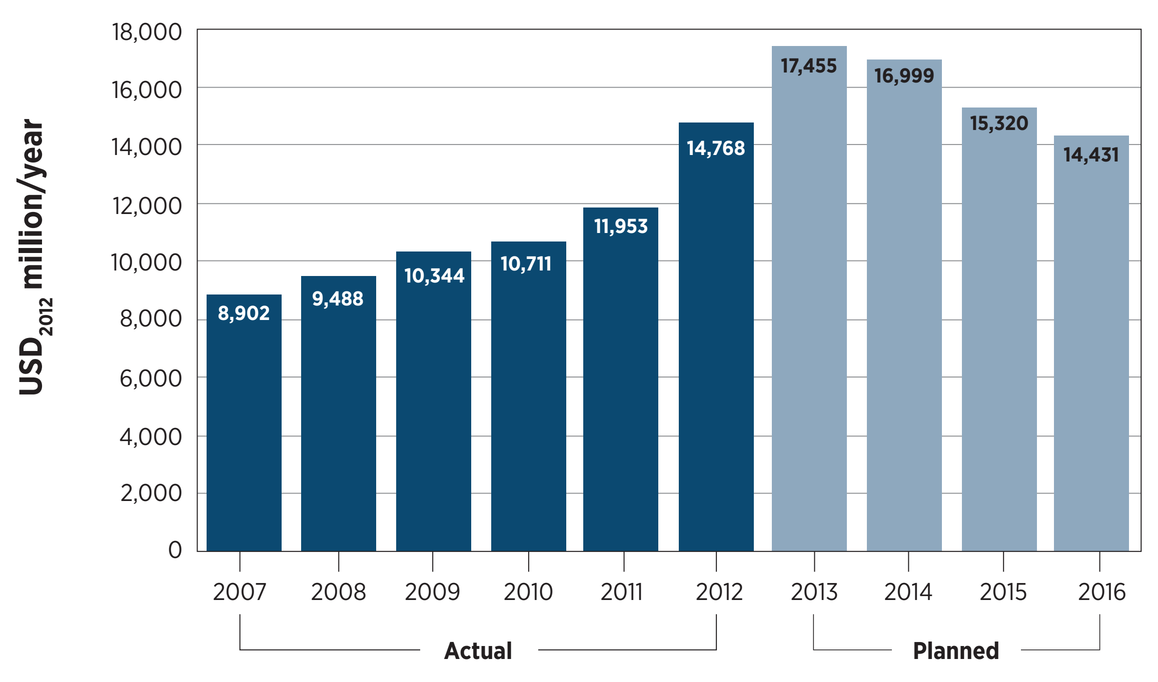
[9] Autoproducer is a statistical term used by the IEA and it is defined as: "Autoproducer undertakings generate electricity and/or heat, wholly or partly for their own use as an activity which supports their primary activity" (IEA, 2013a).

Figure 11: Transmission investment in the US by investor-owned utilities, 2007-2016



Source: EEI (2014)

Note: Data excludes investments by coop, muni, state, and federal power which accounted for in 2009 nearly USD 5 billion (in real 2011 USD) (Jimison and White, 2013).

There are important regional differences. Wind generation is concentrated in the Midwest, hydro is concentrated in Northwest and Northeast. Biofuel production is again in the Midwest. The distribution is related to varying resource endowment

Transmission and distribution grids

Today the US grid consists of 10,000 power plants and 15,000 substations. There are 3,200 utilities that make up the US electrical grid. These power companies sell USD 400 billion worth of electricity a year.

The grid can be split into transmission and distribution grids. The length of the transmission grid is more than 200,000 miles of high-voltage (>230 kilovolts (kV)) and more than 6 million miles of lower-voltage lines. The US electric grid is comprised of three smaller grids. The Eastern Interconnection operates in states east of the Rocky Mountains, The Western Interconnection covers the Pacific Ocean to the Rocky Mountain States, and the smallest covers most of Texas.

Since at least 1988, growth in the US long distance transmission capacity has lagged behind growth in electricity demand. This has not resulted in unmet demand, but in the long run the situation is untenable (APS, 2011). According to recent reports, however, investment in transmission capacity is accelerating. Utilities invested about USD 14.8 billion in 2012 in grid transmission projects (40% of total investments in 2012 to transmission and distribution infrastructure by investor-owned utilities and transmission companies) (Tweed, 2013). It is expected that investments will rise to USD 17.5 billion in 2013, and with “continued high-teens growth in 2013 and 2014” (Figure 11) (Tweed, 2013; Jimison et al, 2014). Investments in electric distribution infrastructure reached USD 20.1 billion in 2012 compared to USD 19.2 billion in 2011 (ELP, 2013).

On the distribution side renewables can help to reduce investment needs. For example solar PV fits well with the peak of air conditioning demand during the day. If the solar is installed on rooftops it reduces grid investment needs. Also remote areas may be serviced with stand-alone or minigrid systems. This is already the case in Alaska; with falling renewables costs this trend may also spread to rural areas of the lower 48 states. Minigrids are projected to grow rapidly in the US.

Since 2010, more than 10,000 automated capacitors, over 7,000 automated feeder switches and approximately 15.5 million smart meters have been put in place. In 2012, the US had around 43 million smart meters installed (US EIA, 2014d). This is about 15% more than the total number in 2011 (FERC, 2013a), and it is projected to grow to 60 million by 2020. Nearly 90% of them are installed in the residential sector (38.5 million) (US EIA, 2014d), where the share of customers with smart meters grew from less than 2% in 2007 to about 15% in 2010. The share of smart meters was 10% in the industry sector in 2010. In most states, smart meter legislations or policies are being considered. In 2010, 11 states had adopted legislation and in three others smart-meter requirements were pending. Of these 11 states, six of them have smart meter growth rates of more than 10% per year (US EIA, 2012c). The American Reinvestment and Recovery Act of 2009 ("ARRA") for the construction and operation of integrated biorefineries (ARRA) allocated USD 4.5 billion to the US DoE for grid modernisation programs of which USD 3.4 billion is related to smart grid investments (FERC, 2013a).

Demand response programmes are also expanding rapidly. They can help to reduce grid cost and they can also help to integrate renewables (Deloitte, 2012). In 2012, demand response measures applied to some 28.3 GW in the markets served by US regional transmission organisations and independent system operators (RTO/ISO) (FERC, 2013a). The PJM Interconnection LLC and the Midwest Independent System Operator (MISO) accounted for 63% of this total.

On November 22, 2013, FERC passed Order 792 Small Generator Interconnection Agreements and Procedures. This order provides the terms and conditions for public utilities to provide interconnection service for small generators (<20 MW_e). The order specifically adds energy storage as one of the sources eligible to interconnect to the power grid (FERC, 2013b). As a result of this order more renewable resources may be connected to the grid.

The smart grids concept includes many technologies. Its use in the renewables context has been described in a working paper prepared by IRENA (IRENA, 2013c).

4 REFERENCE CASE DEVELOPMENTS TO 2030

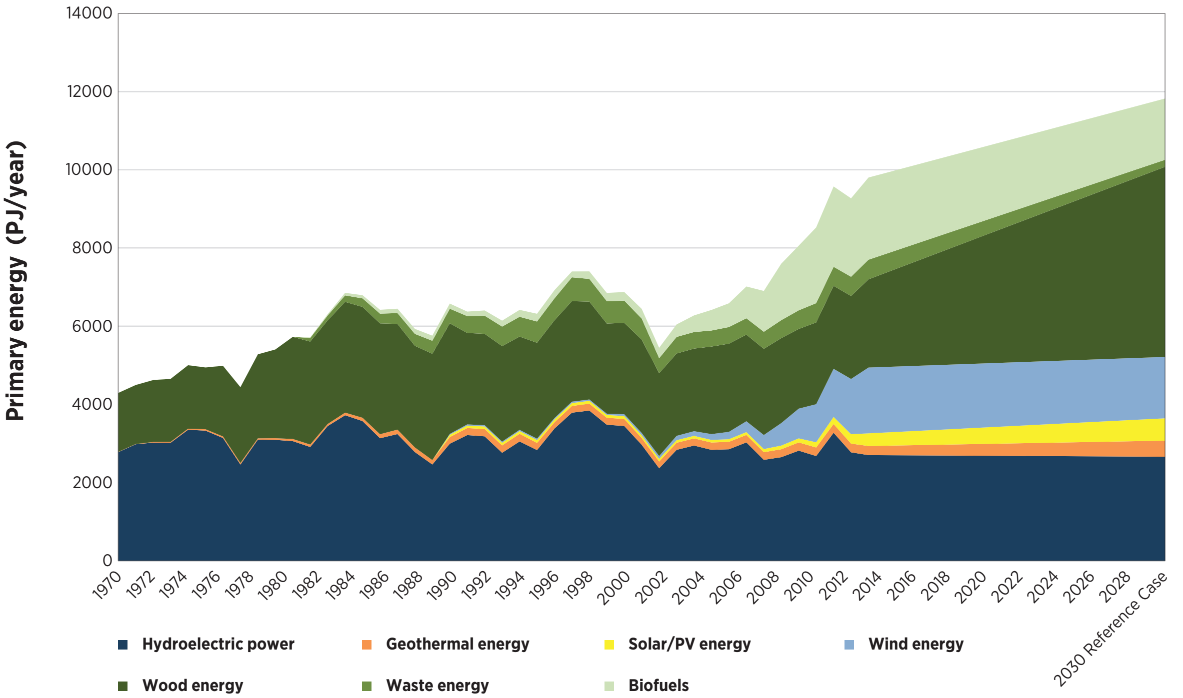
This section explains the Reference Case renewable energy trends in the US between 2010 and 2030. The REmap analysis begins with an assessment of energy consumption projections and uptake of renewable energy technology options between 2010 and 2030 based on current policies. To put this Reference Case in perspective, this section begins with a brief timeline of the US energy demand developments since 1978, the year the Public Utility Regulatory Policy Act was enacted.

The Reference Case from the AEO (US EIA, 2013a) has been used to develop the Reference Case for the REmap analysis. Renewable energy as a percent of TFEC will increase from 7.5% in 2010 to 9.3% by 2020, and to 10% by 2030 (Figure 13). The increase in the Reference Case renewable energy share will be driven mostly by an increase of renewable power generation from 11.4% in 2010 to 16.3% in 2030. The transport sector will see an increase of renewable energy from 4.1% to 6% by 2030, entirely in the form of biofuels. The industry sector will increase from 10.7% to 12.5% and the buildings sector from 6.1% to 6.9% by 2030, both largely driven by biomass.

However, the Reference Case based on the EIA AEO underestimates renewable energy growth in the power sector, and given recent market developments in wind and solar, it is likely that these two technologies will see significantly higher growth by 2030.

In the Reference Case, total power generation is expected to grow by nearly 20% (+739 TWh) from 4,130 TWh/

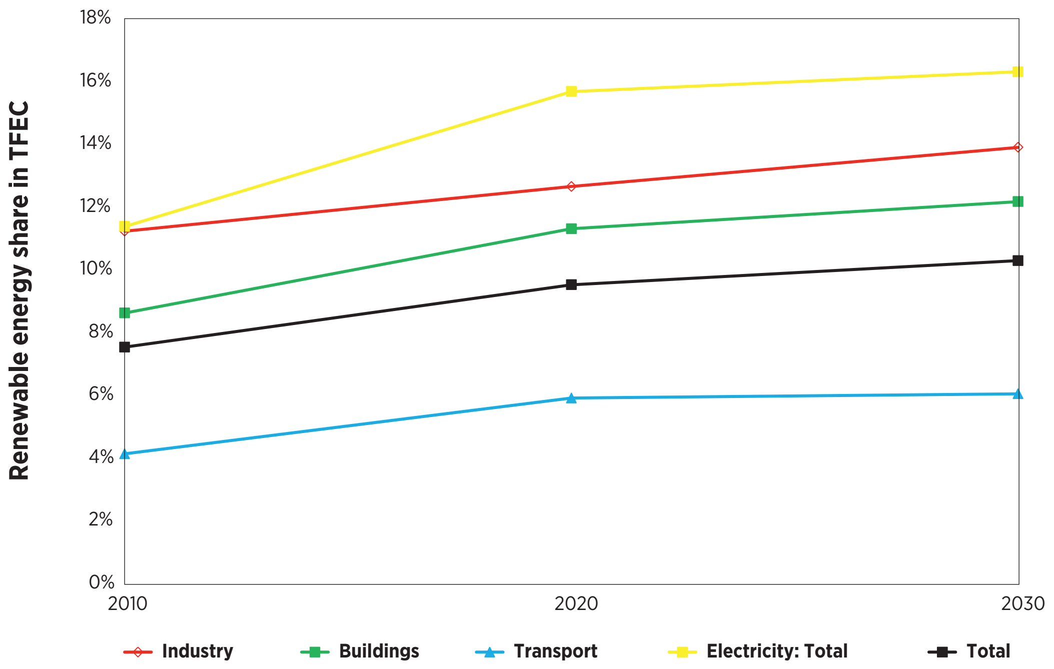
Figure 12: Growth of the total pimary energy supply of renewable energy carriers in the US, 1970-2030



Note: US EIA primary energy accounting method (Substitution Method). 2013-2030 years are linear interpolated to 2030 values.

Source: IRENA analysis of US EIA statistics until 2013, 2013-2030 based on US EIA reference case (2014b)

Figure 13: US Reference Case – Renewable energy shares in TFEC by sector, 2010-2030



Source: IRENA estimates based on US EIA (2013a)

Figure 14: Reference Case renewable power generation growth, 2010-2030

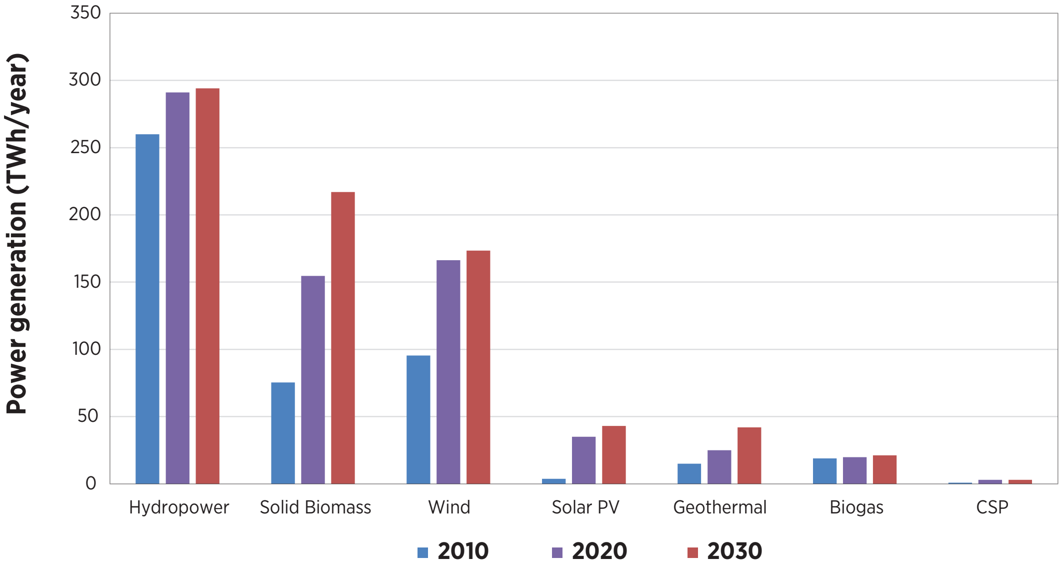
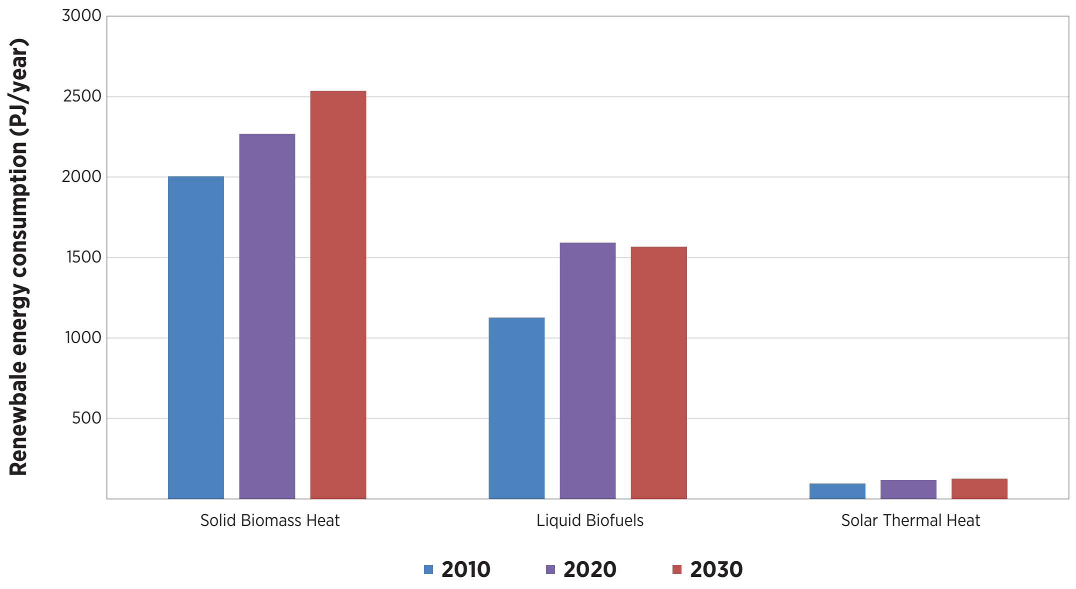


Figure 15: Reference Case growth of renewable energy use in end-use sector, 2010-2030



year in 2010 to 4,870 TWh/year by 2030. Coal generation falls by around 78 TWh between 2010 and 2030. Nuclear increases by 108 TWh and natural gas generation grows by 453 TWh by 2030. Renewable power will increase the second most by 324 TWh (Figure 14).

By 2030, renewable energy will provide 813 TWh of electricity. Hydroelectric generation will total 294 TWh followed by solid biomass with 238 TWh, wind with 174 TWh, solar PV with 43 TWh, geothermal with 42 TWh, biogas with 22 TWh, and finally CSP with 3 TWh. However as stated this projections underestimate recent developments for wind and solar PV.

Renewable energy use in the end-use sectors (Figure 15) sees an increase in biomass heat from 2,105 PJ/year to 2,660 PJ/year in 2030 – almost the entirety of which occurs in industry. In transport, liquid biofuels use increases from about 1,200 PJ/year to 1,567 PJ/year.

In the buildings sector geothermal heating increases from 11 to 22 PJ/year, and solar thermal water or space heating increases from 96 PJ/year to 126 PJ/year by 2030. However these numbers remain modest when compared to the amount of fossil fuel use. Natural gas used in all end-use sectors will increase from 16,300 PJ to 18,080 PJ by 2030 (an increase of 11% in the entire period, or 1,780 PJ), though this estimate may be low due to recent developments. Encouragingly petroleum use in transport will decrease from 27,060 PJ/year by 2,140 PJ to 24,920 PJ/year by 2030.

5 CURRENT POLICY FRAMEWORK

Key points

- Renewables policy in the US has been largely driven by supply security concerns on the federal level, and economic activity and GHG mitigation concerns on the state level.
- On the federal level, the production tax credit (PTC) and investment tax credit (ITC) are the key financial instruments for the power sector. EPA GHG standards announced in June 2014 target new and existing coal plants but may also work to the benefit of renewables by being an important driver for wind energy, along with the PTC and Renewable Portfolio Standards (RPS).
- State level RPS for utilities are another key policy component. These vary widely by state.
- There are various federal policies addressing the production and use of liquid biofuels such as Volumetric Excise Tax Credits (VETC), blending requirements for biofuels, investment subsidies for different sectors for the production and conversion of bioenergy feedstocks.
- There are various federal and state level support for solar water heaters and bioenergy use, but their deployment is mainly left to the markets.

This section discusses the current renewable energy policy framework, split into federal policies and state level policies.

5.1 Federal policies

Under the Obama administration the national energy strategy of the US has been classified an "all-of-the-above strategy". US Federal and some State Governments have strongly supported expanding many forms of renewable power generation in recent years.

On a federal level, reducing the dependence on oil imports is important. Renewables can help to meet this independence as part of an "all of the above" strategy. Innovation is critical to achieve further cost reductions and increase the renewable share. Sustainable bioenergy development, electric vehicles, transition to clean energy technologies including renewables through the Clean Energy Ministerial are all mentioned.

Cellulosic ethanol, drop-in fuels for diesel and jet fuel, and bio-refineries have been promoted through research and development (R&D), fuel standards as well as the funds provided from the American Reinvestment and Recovery Act of 2009 ("ARRA") for the construction and operation of integrated biorefineries.

Relevant Federal Laws include the 1978 Public Utility Regulatory Policy Act ("PURPA"), the Energy Policy Act of 1992 ("Energy Act") and continuous modifications through the Energy Policy Act 2005 ("EPAct 2005"), the Energy Independence and Security Act of 2007 ("EISA 2007") and an amalgam of different Farm Bill documents last updated in 2010. PURPA established the first production tax credits for renewables. The Energy Policy Act of 1992 liberalised the electricity market. The Energy Policy Acts of 2005 and 2007 supported renewable electricity and biofuels. PURPA and Energy Act currently enable 18 states to offer consumers the right to choose their energy provider. PURPA laws also allow for open access to the electrical transmission grid for independent power producers to deploy renewable energy at the utility-scale.

The EPA act 2005 also established renewable energy targets for Federal Agencies, EISA 2007 memorialised E.O. 13423 federal greening requirements into law, and 2009 E.O. 13514 established the immediate requirement for 30% better than ASHRAE 90.1 for all federal designs, the 20% x 2020 energy efficiency gain target for Federal Agencies (currently tracking towards 28% 2020) and set a standard that all Federal buildings that are designed in 2020 are to be net-zero in energy use by 2030. E.O. 13514 alone, has already translated into a 1% efficiency gain to the economy as a whole, and will contribute a 2.8% energy efficiency increase to the US economy overall by 2020.

Added to these are President Obama's "Blueprint for America's Energy Future" (2011), his early 2013 announced goal to double energy productivity by 2030 and his June of 2013 "Climate Action Plan" which builds on the Blueprint targets and broad goals. The approach, is to "deploy American assets, innovation, and technology in order to safely and responsibly to develop more energy here at home and be a leader in the global energy economy" (White House, 2014a). This strategy, encompasses advanced extraction of natural gas and oil, limited nuclear expansion, aggressive energy efficiency in buildings and appliances, improved automobiles fuel efficiency, as well as support for renewable energy. The EPA through its authority to enforce clean air standards, will set more stringent emission requirements for both new and existing coal-fired power plants, and it is currently studying the environmental effects of the extraction of unconventional oil and natural gas. Section 111 of the Clean Air Act establishes emission standards for major stationary sources of dangerous air pollution. Power plants are also included and on June 25, 2013, President Obama directed EPA to use this to curb carbon dioxide emissions from new and existing plants (GPO, 2013). Latter is covered by Section 111(d). Additionally President Obama has set a target of doubling electricity generation from wind, solar and geothermal sources by 2020 and he has directed the US Department of the Interior to permit the development on public lands of enough renewable electricity to power 6 million more homes by 2020 (White House, 2013a).

Also recently agreed to were new CAFÉ standards for cars and trucks that will come into effect by 2025, effectively doubling fuel economy to 54.5 miles per gallon (23 km/litre) which is expected to have a considerable effect on transportation fuel consumption for light-duty vehicles (NHTSA, 2012). The US Department of Energy has put in place energy efficiency standards for appliances, equipment and lighting, including air conditioners, refrigerators and washing machines. More efficiency standards are pending Congressional action for greater efficiency in buildings and industry.

On a federal level there are various policy approaches that support renewable energy. The White House has outlined (White House, 2013b) some broad initiatives to support clean energy development:

- Staying on the Cutting Edge Through Clean Energy R&D
- Promoting Renewable Electricity in Rural America
- Siting Record-Breaking Renewable Projects on Public Lands
- Opening a New Frontier for Atlantic Offshore Wind Development
- Expanding and Modernising the Grid to Integrate Renewables and Increase Reliability
- New Standard for Clean Energy
- Double the Share of Clean Electricity over the Next 25 years from 40% to 80% in 2035
- Investing in Smart Grid Innovation and deploying smart grids
- Investing in DoE's Advanced Research Project Agency-Energy (ARPA-E)
- Syncing R&D Investments and Clean Energy Technology Deployment
- Eliminating Fossil Fuel Subsidies to Help Support Clean Energy
- Doubling the Number of Energy Innovation Hubs to Focus on Key Energy Challenges

A number of federal policies and subsidies supported the renewable power generation capacity deployment such as the production tax credit (created under the EPACT in 1992), investment tax credit, renewable portfolio standards (renewable energy targets for utilities for generation mix), feed-in tariffs, R&D subsidies, funding and guidelines for industrial co-gen, and a North American Smart Grid Interoperability Panel to coordinate and accelerate standards harmonisation.

With PTC, wind projects were able to reduce their annual tax bills by USD 23 per MWh in the first ten years of operation. Solar projects benefit from ITC that is set at 30% of the capital expenditure. Tax credits have helped the US to expand its renewable energy capacity. Once the PTC expired, the next year experienced a slow down in capacity expansion. While the ITC will continue to be applied through 2016, PTC has already expired four times, with the last being at the end of 2013. One option that is considered to improve PTC shortcomings is to set the rate equivalent to the gap between the LCOEs of natural gas and wind based power generation which would eventually reduce to zero over time as the LCOE for wind declines relative to natural gas. However, there are a number of limitations in this approach as LCOE is not a complete metric to express the full costs of power generation and it varies across the country substantially depending on the market variations and resource availability. Furthermore, cost declines may not happen as fast as estimated by models (IRENA, 2014d).

In early December 2014, a bill was passed for the one year extension of the PTC. The extension will apply the same rates. However, only limited impact is expected because of the limited time for projects to meet the eligibility requirements. Furthermore, in the absence of the PTC by end of 2014 reduction in capacity expansion and related jobs are expected .

There are also developments for the creation of a federal Green Investment Bank based on Treasury bonds. The spending limit in the first year would be USD 200 million, followed by spending limit of up to USD 500 million to individual state programmes (CEP, 2014).

In many states rooftop PV has already reached "plug-parity" – matching or even beating the cost of retail electricity. Solar PV is also starting to be able to compete on a wholesale level; electricity sourced from large-scale utility PV farms by local municipal utilities in Palo Alto, CA and Austin, TX has resulting in power purchase agreements in the range of USD 0.05-0.07 per kWh, with the Austin deal including no benefits of the production tax credit (Greentech, 2014).

Inclusion of Standard 189.1 in International Codes such as International Building Code is a critical step to wide-scale adoption of energy efficiency techniques and targets. Standard 189.1 emulates the E.O. 13514's 30% better than ASHRAE 90.1 standard for building designs. Standard 189.1 has already been adopted as a Code requirement in California, Portland, Seattle, NYC, Chicago and DC. It is scheduled to be included in IBC 2014 editions of the International Building Codes. Standard 189.1 requires on-site renewable energy generation equivalent of not less than 20 kWh/m^2 for single-storied buildings, and not less than 32 kWh/m^2 multiplied by the total roof area for all other buildings, with exceptions

As this section shows, in terms of renewables in the power sector, US has a number of policies promoting the growth of renewable energy technologies. In terms of end-use sectors, policies related to the transport focus largely on biofuels, as discussed below. For heating in the building and industry sectors, in addition to tax incentives, R&D subsidies which directly target renewable energy, there are also policies which indirectly relate such as funding and guidelines for industrial CHP. For the energy system as a whole (both the end-use and power sectors), there are no nation-wide targets aiming to reach a certain share of renewables. Targets related to power generation exist in some states only which are discussed in Section 5.2.

Federal biofuels policy

A number of policies, including federal level policies such as the Renewable Energy Production Incentive (REPI) are targeting the increased use of bioenergy (Goh *et al.*, 2013). The first biofuel policy came along with the Energy Policy Act in 2005, RFS1 setting a production target of 7.5 billion gallons of liquid biofuels by 2012. RFS1 was then later amended with the current RFS2 36 billion gallons by 2022 (EPA, 2014a). RFS2 distinguishes between the production of conventional and advanced biofuels, which are defined based on their GHG abatement potential. All biofuels which can save at least 20% GHG in their life cycle compared to petroleum-based equivalents are categorised as conventional. Conventional biofuel production is limited to 15 billion gallons by 2022. Advanced biofuels production accounts for the remaining 21 billion gallons of which 16 billion is cellulosic biofuel (US EIA, 2013c). A biofuel or bio-based diesel can be considered advanced if it saves provide a minimum GHG emission reduction of at least 50%. Cellulosic biofuels provide a minimum GHG emission reduction of 60% compared to the petrochemical equivalent (EPA, 2012).

Biofuel targets are currently under revision with an EPA proposal to cut the 18.15 billion gallons (68.7 billion litres) of biofuels mandated for use by EISA 2007 down to 15.21 billion gallons, still representing an increase of several orders of magnitude over current production levels (final ruling expected in November 2014). Main arguments are compatibility with older cars, small engine wear, and costs for upgrading gas station pumps.

Meeting these production targets and concerns on the GHG performance of conventional biofuels resulted in the deployment of new capacity for advanced biofuels from different feedstocks. New capacity investments also contribute to technological learning and reductions in the costs of production. With more production, advanced biofuels are expected to improve their economic viability in the near future and contribute further to the US transport sector fuel mix.

Box 2: Energy efficiency in the US

The US is experiencing significant progress in the development of new energy efficiency policies. The Energy Efficiency Improvement Act of 2014 (HR 126) which passed on 5 March, 2014 for improving energy efficiency of the buildings us just one of them (ACEEE, 2014a). On 9 May, 2014, President Obama announced an additional goal of USD 2 billion in federal energy efficiency upgrades over the next 3 years. Combined with the commitment of USD 2 billion in 2011, this is a total of USD 4 billion in energy efficiency investments through 2016 (White House, 2014b). Different drivers play a role in the development of US energy efficiency policies, such as energy security, grid reliability or air pollution.

Each end-use sector has its own potential and challenges in terms of improving its energy efficiency. The energy use and structure of the US building sector is an interesting case compared to other countries. The typical lifetime of the buildings in the US is between 50 and 60 years old. This is a reason which limits the capital stock turnover. The floor area of both residential and commercial buildings is large (high floor area per capita) compared to other countries with similar income levels. Furthermore, appliance use accounts for a large share of the sector's total energy demand and it has been one of the main reasons why the building sector energy use has increased substantially in the past years. Energy efficiency of buildings (themselves) and appliances are governed by codes and standards at the federal level, whereas at state level there are building codes. State-level codes regulate the different types of demand in buildings and in some states codes also exist for renovation of the existing stock. Buildings and appliances are subject to energy labeling indicating their level of energy efficiency according to federal policy. In addition, a number of voluntary initiatives (*e.g.,* Energystar; Home Energy Rating System) are also becoming commonly used (CPI, 2013).

By 2030, estimated techno-economic energy efficiency improvement potential in the building sector is 30% for the residential sector, and 35% for the commercial sector. This estimates the total saving potential of electricity and natural gas compared to the business-as-usual estimates for 2030 (Brown *et al.*, 2008). New buildings are expected to account for only a quarter of the total floor area of the US building stock by 2030 (CPI, 2013). This creates an important opportunity to reduce the building sector energy demand. Retrofits of the existing building stock will also play a very important role. A recent report from The Rockefeller Foundation and the Deutsche Bank (2012) quantified the current market size of retrofitting the US buildings. According to the report, upgrading and replacing energy-consuming equipment would save up to USD 1 trillion energy savings over 10 years which would require about USD 279 billion investment across the residential, commercial and institutional buildings. Two-thirds of this investment potential exists in the residential sector.

As with buildings, the manufacturing industry sector has an aging capital stock. However, as a result of low-cost natural gas availability investments in natural gas-intensive industries such as chemicals industry are expanding. While this raises significant potential for investing in best practice industrial energy efficiency technologies, low energy prices, which make up an important share of the total production costs in some sectors, could limit the full deployment of this potential. With best practice technologies, there is a techno-economic energy saving potential of up to 15% in the US industry (UNIDO, 2010). Industrial energy efficiency programs differ from state to state, and also within states. While some states require all cost-effective technologies to be deployed within a given sector, others focus on reducing the demand for specific energy carriers such as natural gas or electricity via different measures (SLEEAN, 2014). "Save Energy Now", "Superior Energy Performance", "Energy Star for Industry" are among the different federal level programs addressing industrial energy efficiency in the US (Griffith, 2012).

Energy efficiency in the transport sector is an issue which has received somewhat less policy attention, however, there are still a number of nation-wide energy efficiency related standards. In 2011, the US has adopted a fuel efficiency standard for medium- and heavy-duty freight trucks that already account for 20% of the transport sector's TFEC, and whose fuel demand is growing faster than any other sector in the US (ACEEE, 2014b;c). The aim is to reduce 10-24% of the total fuel demand by 2017 compared to 2010 levels. The potential to improve the energy efficiency of the non-light duty vehicles ranges from 25-50% for trucks to 50-75% for marine and aviation modes (Vyas, Patel and Bertram, 2013).

In addition to the benefits of improving energy efficiency alone, there are synergies with the deployment with renewables. The same amount of renewables results in a higher share of renewables based on a lower TFEC. Furthermore, some renewable energy technologies offer the potential of improving energy efficiency as well, such as electric vehicles (more efficient by a factor 2 compared to internal combustion engines) or heat pumps (nearly three times more efficient than the most efficient condensing natural gas boilers).

A number of other policies support the deployment of liquid biofuels, such as the VETC for fuel ethanol and biodiesel blending or subsidies for capital investment support, construction of biofuel plants, and other infrastructure (Lamers *et al.*, 2011). VETC alone provides the largest subsidy to both ethanol and biodiesel (Koplow, 2007). At the feedstock level, the Biomass Crop Assistance Program (BCAP) which started in 2009 aims at the increased use of agricultural and forest products. BCAP provides incentives for the establishment, production and delivery of biomass feedstocks for owners and operators of agricultural land and non-industrial private forest land (USDA, 2013).

As discussed in Section 3, as a result of these policies the became a large producer and consumer of solid and liquid bioenergy commodities. Bioenergy production and use for power generation and heating is expected to continue as well.

In May 2014, President Obama called for commitments to improve energy efficiency and solar deployment. Building a skilled solar workforce is one of the actions of this commitment. US DoE's Solar Instructor Training Network will support the training of 50,000 workers to be employed in the solar industry by 2020. This complements the SunShot initiative's achievement of training 22,000 people since 2010 (White House, 2014b).

Greenhouse gases

GHG emission reduction is another key policy component. This is achieved through various policies that amount to a *de facto* ban on non-carbon capture and storage coal power generation (air pollution, carbon intensity standards). The Administration's strategy is to restrict coal power generation by imposing new stack emission standards through a combination of new EPA actions including Mercury and Air Toxics Standards (MATS) regulations as well as now, for the first time, developing Carbon Emission standards. These carbon standards apply to new coal power plants, effectively stopping new construction. As mentioned in the memorandum from June 25, 2013, the EPA has been directed to use its authority under Sections 111(b) and 111(d) of the Clean Air Act to address carbon emissions from existing power plants. Proposed carbon pollution standards, regulations, or guidelines for existing power plants were to be issued latest by June 1, 2014. They will be finalised by June 1, 2015 (GPO, 2013).

On 2 June 2014, the EPA released a draft rule proposing limits on carbon pollution from existing fossil fuel power plants (EPA, 2014b). According to this rule, EPA will be taking steps to realise carbon emission reductions from the power sector. The proposal includes an analysis of two options, and the EPA's recommended option is the more stringent of the two. EPA estimates that this option would result in nationwide emissions reductions of up to 27% by 2020 compared to 2005 levels, 29% by 2025, and 30% by 2030. 2030 emission reduction is equal to the emissions from powering more than half the homes in the US in one year. Besides GHG emission reductions, PM pollution, NO_x, and SO_2 emissions should be reduced by more than 25% as a co-benefit in the same period. According to the Administration, the Clean Power Plan will lead to climate and health benefits worth between USD 55 billion to USD 93 billion in 2030, and result in 2,700 to 6,600 fewer premature deaths and 140,000 to 150,000 fewer asthma attacks in children (EPA, 2014c). The Clean Power Plan will be implemented through a state-federal partnership allowing significant flexibility to states to detail how they will meet the goals of the new program.

The EPA is seeking public comment on the proposed rule, as well as variations on the proposed rule. The comment period will last for 120 days from the date of official publication of the proposal. After that, the EPA will analyse and respond to the comments, and can make adjustments to the proposed rule prior to finalising the rule. This process is expected to be done by the middle of 2015. This approach of having public comment on multiple options for a rule, followed by additional analysis and revision by an agency, is the way US agencies generally do regulatory rulemaking.

Based on the Clean Air Act, the proposed rule establishes a "best system of emission reductions (BSER)" based on an analysis of opportunities available in the electricity sector to reduce emissions, focusing on four building blocks: 1) reducing heat rates in existing power plant facilities; 2) increasing the utilisation rates for existing and under construction natural gas combined cycle power plants; 3) accelerating deployment of renewable energy and ensuring that existing nuclear energy remains in operation; and 4) reducing energy demand through energy efficiency.

Box 3: Renewable energy in California

California is one of the most ambitious states in the US in terms of energy efficiency and renewable energy. At the same time it's a large economy by itself and provides valuable insights on how to structure a transition.

California's per capita electricity demand has been stable during the past 40 years. However population has increased during this period. Gross demand stood at 296 TWh in 2013 and has been stable during the last decade. The state accounts for nearly 8% of national demand.

California's generates more than 200 TWh of electricity per year. In 2011, California produced 70% of the electricity it uses; the rest was imported from the Pacific Northwest (10%) and the US Southwest (20%). In-state renewables generation share stood at 30% in 2013 including hydropower. Hydropower accounted for nearly half of all renewable generation (CEC, 2014).

State power generation capacity stood at 73 GW_e in 2012. Natural gas is the main source for electricity generation at 60% of the total in-state electric generation. The state had 15.9 GW_e hydro, 6.5 GW_e wind, 3.5 GW_e solar, 2.8 GW_e geothermal and 1.1 GW_e landfill gas and bioenergy power generation capacity in 2013 (CEC, 2014). Main growth in recent years has been in solar and wind while hydro and geothermal are stable. The state accounts for 80% of US geothermal capacity and has been a leader in CSP: the state has 354 MW_e of solar thermal power capacity that has been in operation for 30 years. 4.2 GW_e of solar thermal capacity have been approved and 1.5 GW_e additional solar thermal capacity is under review. But many projects have been withdrawn or have met planning problems. Nearly 0.9 GW_e of solar thermal capacity is under construction (ACORE, 2014a). In 2002, California established its RPS Program, with the goal of increasing the percentage of renewable energy in the state's electricity mix to 20 percent of retail sales by 2017. The 2003 that goal was increased to 20 percent by 2010, and the 2004 a further recommended increasing the target to 33 percent by 2020. The state has now an ambitious target of 25% renewable retail sales by 2016 and 33% renewable electricity by 2020 (excluding large hydro), more than a doubling. California is on its way to exceed the RPS for the period 2014-2016 by 15%.

Transmission expansion is a priority to enable interconnection and deliverability of renewable electricity. California has over 1 billion litres (264 million gallons) per year of renewable fuel generation capacity, 72% ethanol. The objective is 1.5 million zero-emission vehicles by 2025, including one million battery electric vehicles. This equals around 5% of total motor vehicle stock.

There is a programme in place to support solar water heaters and rooftop PV systems. The objective is to install 3 GW_e rooftop solar PV by 2016 and 585 million therms of solar hot water systems by end of 2017. The State-wide budget is USD 3.6 billion (ACORE, 2014a).

Apart from RPS and subsidies for rooftop systems policies in place include net metering, subsidies for self-generation and renewable energy auctions (ACORE, 2014a).

Under the proposal, EPA establishes state-specific goals for the power sector's carbon intensity, and provides states with options for meeting those goals in a flexible manner that accommodates a diverse range of state approaches, which can including working together with neighboring states to develop multi-state plans.

In its proposal, EPA requests comment on many aspects of the rule, including, for example, whether states should be able to implement the rule in concert with other states, on its assumptions about what constitutes the "best system of emission reductions," and on the two alternative options and their assumptions. EPA also takes comment on a range of BSER assumptions that could substantially affect the stringency of the 10-year or the 5-year options, depending on feedback received in the public comment period.

In November 2014, the US together with China announced GHG emission reduction goals. By 2025 the US plans to reduce its CO2 emissions by 26-28% compared to 2005 levels. These targets are similar to what has been envisioned in the 2009 American Clean Energy and Security Act and can be seen as an extrapolation of the reductions of 17% planned for the year 2020.

5.2 State level policies

State policies are a major driver (notably in states such as California, Colorado, Texas, New Jersey, and Hawaii) (see ACORE, 2014a, for an overview). Much of the US energy supply has been coordinated on a regional level where states, counties and cities have a wide variety of initiatives to support renewable energy development. Leaders include California and Colorado where Public Utility Commissions are strong and resources are plentiful, but some states are much less supportive of renewable energy, specifically in the Southeast of the US. However these states have high renewable energy potential, particularly with biomass, small hydro and PV, and efforts should be made to develop this resource potential.

Table 1: Select Renewable Portfolio Standards for power generation

State	Renewable Power (%)	Year
Hawaii	40%	2030
California	33%	2020
Colorado	30%	2020
Connecticut	27%	2020
Minnesota	25%	2025
Illinois	25%	2025

Source: DSIRE (2013)

As of 2013 RPS, or Renewable Electricity Standards, have been developed under federal agencies by 29 States and Washington DC (8 additional states have voluntary standards or goals) (DSIRE, 2013; C2ES, 2014). When combined, these states generate up to about 70% of total US net power. RPS is one of the most successful approaches that requires local utilities to supply to consumers a certain percentage of their power from renewable sources (see Table 1). Some states have adopted federal energy efficiency standards as well. However, it should be noted that several states are considering repeal or suspension of these standards, and at least one state has already done so.

State level renewable portfolio standards for utilities are another key policy component. These vary widely by state

In addition to the federal policies renewable portfolio standards, there are various other state level tax credits and grants regarding the increased use of different bioenergy commodities (UNECE, 2011). Financial incentives are typically used to support feedstock demand, supply and lower costs of capital and they are not limited to bioenergy necessarily, but cover other renewable energy source as well.

While there are targets aiming to increase the use renewables in power generation and biofuels in the transport sector, with regarding to heating and cooling, support from the level of federal or states for the wider use of renewables, including biomass, is limited (UNECE, 2011).

Since September 2009, nine states[10] are participating in the Regional Greenhouse Gas Initiative (RGGI). RGGI

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[10] The nine states participating in RGGI are: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island and Vermont.

aims to reduce greenhouse gas emissions from power plants through a cap and trade program (RGGI, 2014). The program, which is the first mandatory market-based CO_2 emission reduction program in the US, was reviewed in 2012, and the current cap is 91 million short tons which will annually decline by 2.5% between 2015 and 2020 (RGGI, 2014). The aim is to reduce electricity sector emissions by 2020 to 45% below the 2005 levels. California also instituted in 2012 a cap-and-trade programme for CO_2 that envisions reducing emissions

Box 4: Renewable energy in Hawaii

Hawaii has a target of 70% energy independence by 2030. Within the 70% goal, locally generated renewable sources will account for 40% of total energy consumption, while achieving greater energy efficiency makes up the remaining 30%. The policy is based on scenario analysis (NREL, 2011).

Hawaii had 700 MW_e renewable power generation capacity in 2012. Biomass, solar and wind are all around 200 MW_e, supplemented by smaller amounts of geothermal and hydropower. Renewables account for 14% of electricity generated in 2012 (State of Hawaii, 2013). Demand stands at 10 TWh and solar PV in particular is growing rapidly. The state has around 14 TWh of renewable electricity potential, including more than 7 TWh of geothermal on the main island Hawaii and more than 2.5 TWh of wind with a very high capacity factor on all six islands (State of Hawaii, 2012a).

The target is 40% renewable electricity by 2030. Island interconnectors are being established as resources are not evenly distributed; Oahu in particular lacks resources and sites to economically move beyond 25-30% renewable energy on its own.

There is a strong economic incentive. Electricity prices in Hawaii were USD 0.32 per kWh in 2011, the highest of all US states (State of Hawaii, 2012a). Such high prices are typical of islands with oil based power generation.

A net metering system is in place. There are tax rebates for solar and wind installation. Three utilities offer feed-in tariffs, there are concessional loans for PV, wind, biogas and biofuel projects by farmers and aqua-culturists.

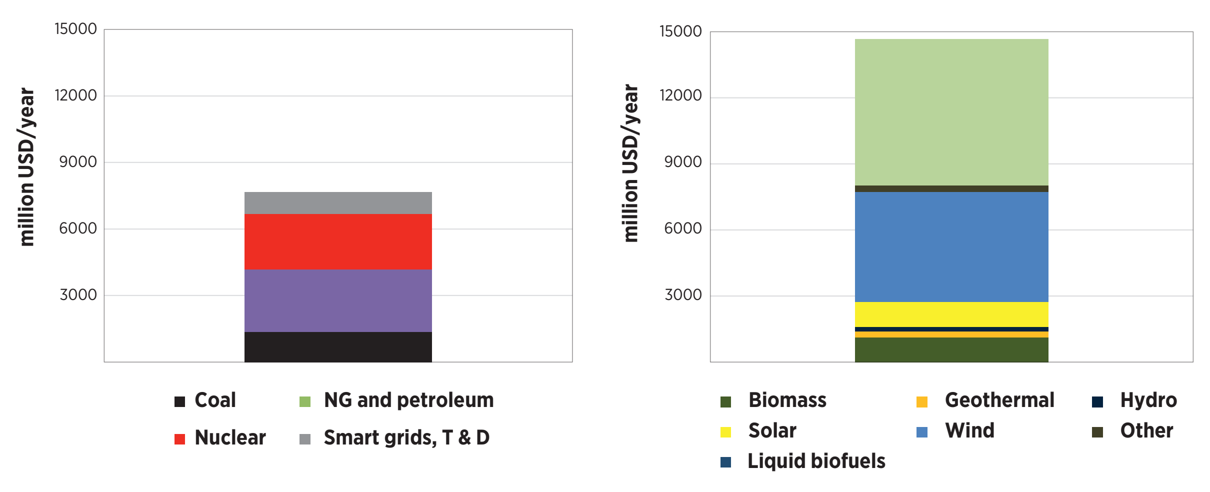
There is a rebate system in place to support solar water heaters (USD 750-1000 per system). Also there is an E10 standard, and Alaska Airlines will introduce locally grown biofuels from 2018.

Hawaii had 1500 EVs and nearly 16 000 hybrid electric vehicles (HEVs) in 2013. There is an EV project in place on Mauii, in cooperation with NEDO from Japan (State of Hawaii, 2013).

Each year, Hawaii uses between 1.7 and 2.2 billion gallons of liquid petroleum fuels. Hawaii has favorable highway tax rates, an ethanol blending mandate, an ethanol facility tax incentive, and an alternative fuel standard that sets a target of 20% of highway fuel demand to be supplied by alternative fuels by the year 2020. Since 2000 there is an objective of 40 million gallons per year of in-state biofuel production capacity. A recent study indicates that a biofuels industry of between 100 and 300 million gallons per year beyond 2023, representing about 10% of liquid fuel demand, appears to be both significant and achievable (State of Hawaii, 2012b). However this will require significant buildup of celluloses ethanol, algae, drop-in fuel capacity for aviation etc.

In a nutshell, Hawaii reflects the issues for the much larger US energy system. However much higher fossil fuel and electricity prices that can be attributed to the island conditions exacerbate the problem and create a strong incentive for a transition. At the same time the state benefits from the R&D and innovation capacity of the mainland. This makes Hawaii a unique test bed that can also provide valuable insights for other islands countries and territories.

Figure 16: Comparison of the direct federal financial interventions and subsidies in the energy sector of the US, 2010



Source: IRENA analysis of US EIA (2011)

to 1990 levels by 2020. In comparison to RGGI which focuses on the power sector only, the programme in California covers electricity generators, CO_2 suppliers, large industrial sources, and petroleum and natural gas refineries as well (SEE, 2013). California has the most developed marketplace for cap-and-trade of CO_2 and has successfully has auctions for large emitters of CO_2. It is expected that by January of 2015 the cap-and-trade law will also apply to petroleum used in the transport sector, which in 2014 was estimated at 53 billion litres (14 billion gallons), and could add between USD 0.15-0.20 to the price per gallon for motor fuels. California would become one of the first regions in the world to put a price on carbon emitted in the end-use sectors (with the exception of large industrial emitters) (CW, 2014).

Renewables policy in the US has been largely driven by supply security concerns on the federal level, and greenhouse gas mitigation and economic activity concerns on the state level

There is a large number of other state and local programs designed to promote a wide variety of renewables, but these all cannot be listed in this report. A source for information on these programs can be found at http://www.dsireusa.org/.

As opposed to some EU countries, climate change historically played a rather small role in the US federal level renewable energy policy, although this is changing. Other issues played so far a more important role compared to climate change among all environmental issues (Elliott, 2013). In the case of some specific states which focused on GHG mitigation, designing renewable energy policies gained priority (*e.g.,* California). Economic activity is another reason why there are state level renewable energy policies (UCS, 2013).

5.3 Conventional and renewable energy subsidies

National and international organisations provide estimates of the subsidy levels in the US for fossil fuel and renewable energy sources. The US EIA (2011) provides a snapshot of the *direct federal financial interventions and subsidies* in the energy market for the year 2010. In the energy sector, a total of approximately USD 22 billion of intervention and subsidies were provided (excluding conservation and end-use subsidies with a total of USD 14.8 billion). Much of this total is tax expenditures[11] (USD 12 billion), followed by direct expenditures to producer

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[11] According to US EIA (2011), these are "...provisions in the federal tax code that reduce the tax liability of firms or individuals who take specified actions that affect energy production, consumption, or conservation".

and consumers of energy (USD 5.2 billion). R&D related intervention and subsidies amounted to USD 3.5 billion with the remainder USD 1.2 billion being related to loans and loan guarantees and electricity programs targeting specific consumer groups.

According to the EIA total subsidies in the US (excluding conservation and end-use) has increased by about 60% between 2007 and 2010, from USD 13.9 to USD 22.3, respectively. The increase in total electricity related and non-electricity related were similar to the total.

In 2010, conventional fuels (coal, natural gas, petroleum products and nuclear) accounted for 30% of the total (USD 6.7 billion). 66% is related to renewables for power and heat generation as well as liquid biofuels (USD 14.7 billion). Total federal direct subsidies in the US renewable energy sector were more than double compared to fossil fuels in 2010. When excluding subsidies for biofuels, more than 80% of the renewable subsidies were related to power generation.

Liquid biofuels (USD 6.6 billion) and wind (USD 5 billion) accounted for nearly three-quarters of the total subsidies in the renewable energy sector. Solar and biomass received each USD 1.1 billion per year.

Subsidies related to tax expenditures account for more than half of the total subsidies in the renewable energy sector (USD 8.2 billion, 55%), followed by subsidies for direct expenditures to producers and consumers of energy (USD 4.7 billion, 32%).

Compared to the relatively new renewable power industry, the conventional power sector has enjoyed a long historical learning curve to develop cost-effective generation. Incentives to accelerate the renewable learning curve could be helpful to hasten and broaden the switch to renewable energy technologies. According to the estimates of a study by Koplow (2013), master limited partnerships (MLPs) are often excluded from federal assessments of energy subsidies. MLP is a special category of business partnership structure which is dominated by oil and gas companies. MLPs avoid corporate level incomes taxes and distribute to cash to owners on a tax-deferred basis. This creates a disadvantage in electric, heating and liquid fuel markets for renewables. According to the same study related tax subsidies are as high USD 4 billion per year in recent years. When adding this total to existing estimates of subsidy to conventional fuels, the total amount is nearly as high as the levels for renewables.

5.4 Cost and benefits of existing policies

Understanding the cost and benefits of existing policies is essential for policy-makers to be able to evaluate these policies and ensure that necessary modifications are done. RPS is in place in more than half of the US states and in many for longer than half a decade. To date, many studies have looked into the assessment of the cost and benefits of RPS. According to Heeter *et al.* (2014), average incremental RPS compliance cost in the US was equivalent to 0.9% of the retail electricity rate, with the average ranging from 0.1% to 3.8% in restructured markets to between -0.2% and 3.5% in traditionally regulated states. Emission or human health benefits of RPS policies translate to USD 4-23 per MWh for renewable power generation, depending on the cost value assumed in the studies surveyed. In terms of the benefits over the lifespan of the projects, estimates show a range between USD 22 and 30 per MWh. Finally, wholesale price reductions of about USD 1 per MWh or less have been achieved, or price suppression benefits of between USD 2 and 50 per MWh.

Carley and Browne (2012) conducted a literature review to identify to explain the reason of the widespread adoption of RPS – one of the dominant drives of renewable power uptake. They found the causes include intrastate environmental features, local air pollution, high power demand growth, cost-effective wind production potential, differences in states' natural resource endowment as well as the role of economic and political factors such as gross state product per capita, state legislature partisanship and ideology, and state-level citizenship ideology.

Their study also elaborates on the effectiveness of RPS. According to some case studies, RPS results in an uptake of renewable power generation in specific locations and it also results in competition between renewable energy producers, *e.g.,* wind in Texas. The policy also result in the diversification of the electricity mix portfolio, however, in the case of California non-hydro uptake resulting from RPS was limited. One important finding is that RPS results in renewable energy in new capacity investments as opposed to the substitution of existing capacity. Hence this may result in rather modest increases in the renewable energy share of a state's total energy mix. The results of a number of models based on state-level data (from 1998 to 2006), RPS is found to encourage renewable energy investment and deployment (Carley, 2009). However, RPS is not in all cases an effective instrument to result in high shares of renewables in the energy mix of electricity.

Some states are not on track to reach their RPS targets and they are also not achieving the intermediate benchmarks as a result of the noncompliance from participating utilities. Noncompliance is found to originate from low financial penalties, limitations in transmission capacity and other procurement limitations. For example, siting difficulties for new renewables capacity and expansion of the transmission grids acted as a barrier. One important finding is that as of 2011 more than 90% of all new RPS was from wind. This may limit diversifying the portfolio of generation technologies and also the future viability of technologies which are emerging today.

Many states have added carve-out and credit multiplier features to RPS with the aim of helping diversification and R&D which produced positive results, for example in the cases of centralised and small-scale solar PVs.

RPS has electricity price impacts and compliance costs. Empirical research showed that electricity price increases are negligible or modest from RPS implementation. Palmer and Burtraw (2005) analysed the potential effects of policies to promote renewable sources of electricity in the US. According to their findings to 2020, RPS would raise electricity prices only minimal and primarily reduce gas-fired generation. A PTC would lower electricity prices at the expense of taxpayers, which limits its effectiveness in reducing carbon emissions, and it is less cost-effective at increasing renewables than a RPS. Chen *et al.* (2007) analysed the results and methodologies of 31 distinct state or utility-level RPS cost-impact analyses completed since 1998 which represents RPS in 20 different states. The majority of the studies project modest cost impacts. The results of almost three-quarters of state-level cost studies show that RPS will have little impact on retail electricity rates, which are expected to see increases no greater than 1%.

According to Carley and Browne (2012), compliances costs faced by utilities are insignificant due to the PTC, substantial wind power potential and a sizeable RPS target with low levelised cost of electricity (LCOE) (due to economies of scale). For the case of solar, it is different because solar carve-out and RPS compliance costs sometimes conflict, where obligation to install solar increased the cost of RPS compliance. This trend is now changing with the latest large-scale utility projects becoming more cost-competitive.

The study by Wei, Patadia and Kammen (2010) focused on the socio-economic benefits from clean energy technology deployment. According to the findings of this study, aggressive energy efficiency measures combined with a 30% RPS target in 2030 can generate over 4 million job-years by 2030 while increasing nuclear power to 25% and carbon capture and storage (CCS) to 10% of overall generation in 2030 can yield an additional 500,000 job-years (Wei, Patadia and Kammen, 2010). The result is that renewable energy can create seven times more jobs than a nuclear/CCS low carbon pathway.

6 RENEWABLE POTENTIALS AND THEIR COSTS TODAY

Key points

- The US is blessed with abundant resources of all types of renewable energy. Wind and solar resources are some of the most abundant in the world.
- Shifting energy consumption in the end-use sectors from fossil fuels to renewable electricity provides a means of increasing the utilisation of the significant renewable power potential.
- The US bioenergy resources account for around a fifth of the world resource potential and the potential equals nearly a quarter of the national energy use,
- Hydropower resources have already been used to a significant extent though additional potential exists with upgrading potential and adding power generation to non-powered dams
- Biomass supply costs vary from USD 1 to more than 10 per GJ depending on the type of biomass. Transportation of biomass over long distances will raise these costs as bioenergy use increases.

6.1 Renewable power generation options

Table 2 provides an overview of technical potentials for renewable energy in the power sector according to a recent NREL assessment (2012b). With the exception

Table 2: Renewable energy resource potentials of US

	2012 Capacity	2012 Generation	Technical potential (NREL)		REmap 2030		REmap 2030 / Technical potential	
	GW_e	TWh/year	GW_e	TWh/year	GW_e	TWh/year	% of GW_e	% of TWh
Solar PV (rooftop)	5.4	8.0	665	819	45	75	7%	9%
Solar PV (utility, urban)	1.9	3.6	1 218	2 232	89	159	7%	7%
CSP	1	1	38 066	116 146	2.4	8	0.01%	0.01%
Wind (onshore)	60	140	10 955	32 784	314	994	3%	3%
Wind (offshore)	0	0	4224	16 976	42	160	1%	1%
Biopower (solid) (production)	12[1]	50	51	400	74	401	145%[1]	100%
Biopower (gaseous) (production)[2]			11	89	4	89	38%	100%
Geothermal (hydrothermal)	3	15	38	301	24	184	63%	61%
Geothermal (EGS)			3 976	31 345				
Hydropower[3,4]	78	276	153[5]		114	431	75%[5]	

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1 2012 biomass power capacity according to the EIA includes 3 GW_e municipal waste and 3 GW_e wood biomass and excludes plants under 1 MW_e. Other estimates that include smaller plants estimate capacity around 12-15 GW_e.

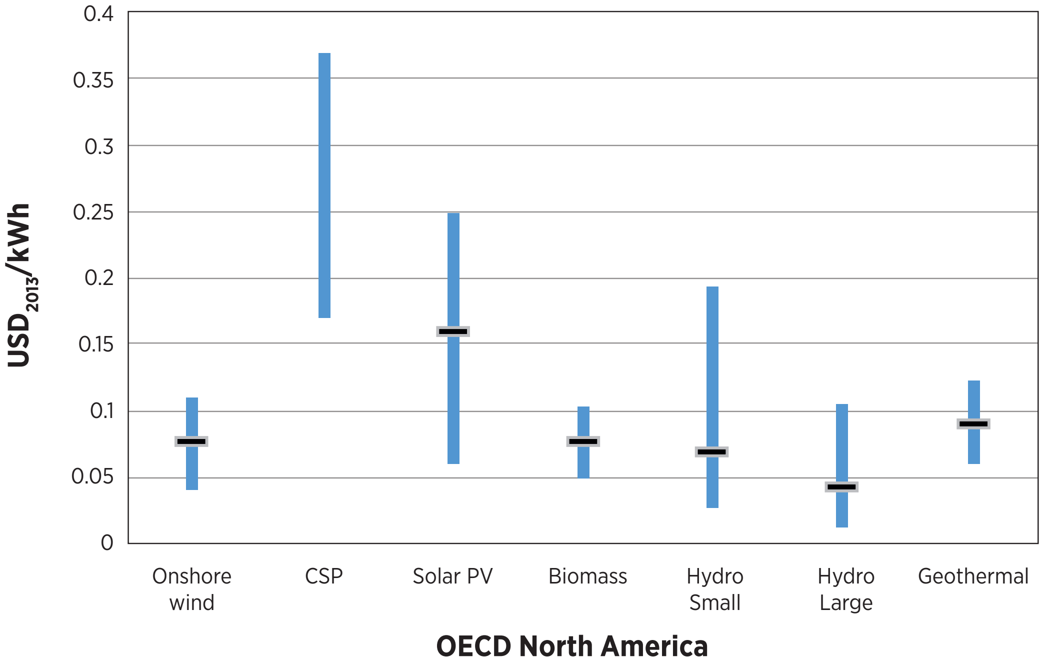
2 Technical potential based on the study by NREL would depend on the amount of biomass which would be available for power generation next to other markets.

3 Comparison only of REmap Options for Hydropower and INL technical potential of non-dam/reservoir potential. No additional dam/ reservoir Options were considered for REmap.

4 All values exclude pumped-hydro (approx. 20 GW_e) and small hydro (7 GW_e)

5 Technical potential based on Hydropower & Dams (2013).

Figure 17: Typical LCOE ranges and weighted average for renewable power technologies



Source: Based on figure in IRENA (2013d), solar PV updated in 2014

Note: Assumes a weighted average capital cost of 10%. All results presented exclude subsidies, unless explicitly mentioned. These are LCOEs and among different approaches, LCOE is one way to examine the cost-competitiveness in a static analysis. LCOEs do not substitute for the need to do detailed, nodal modelling of the electricity system if one wants to identify the least cost combination of new generating capacity, type and location to achieve a least cost expansion or maintenance of the electricity system, note this should also include analysis of the demand-side such as efficiency and demand-side management options.

of hydropower and biomass, all renewable power technologies identified in the REmap Options fall well below the technical potential identified by NREL. For hydro, NREL's assessment is below the current capacity of nearly 80 GW$_e$; however different assessments have come up with much higher potentials. For example, one assessment mentions technical and economic hydropower potentials at 153 GW$_e$ and 100 GW$_e$, respectively (Hydropower & Dams, 2013).

Hydropower resources have already been used to a significant extent though additional potential exists with upgrading potential and adding power generation to non-powered dams

Biomass power also exceeds the technical potential identified by NREL. Since biomass power production is dependent on the amount of available fuel, another way of assessing technical resource potential is to look at the availability of biomass. IRENA analysis determined the US has a 19-23 EJ of supply potential, and only 16 EJ is used in REmap, therefore the power production total for biomass falls within the technical supply potential according to IRENA estimates.

The US is blessed with abundant resources of all types of renewable energy

Excluded from Table 2, are tidal energy resources for power generation which have potential ranging from 0.9 TWh/year in Western Passage, Maine up to 2.1 TWh/year in Golden Gate California. Admiralty, Washington also has a high estimated potential of 1.7 TWh/year (US DoE, 2009). Federal Energy Regulatory Commission (FERC) approved a ten-year license for the 600 kW$_e$ experimental tidal project at Admiralty, which will be connected to the grid (FERC, 2014).

In some parts of the country renewable power generation technologies can already compete with conventional generation based on cost alone. IRENA's Renewable Power Generation Costs report shows (see Figure 17) that wind power can already generate electricity without subsidy for as little at USD 0.04 per kWh of LCOE in certain areas, making it competitive with, or cheaper than, new gas-fired generation (IRENA, 2013d; Dedrick, Kraemer and Linden, 2014). In other parts of the country, without the production tax credits, the US wind industry would need to drive down costs of the projects itself to ensure economic viability. This is especially a challenge for the offshore wind. The European counterparts who are more experienced in the offshore wind sector have targeted cost reductions for 2020 which are still much higher than the expected costs of production from gas and other fossil fuels in the US (CEP, 2014).

6.2 Biomass supply potential

Compared to many other countries, the US is experienced in carrying out bioenergy resource assessments. Based on the key studies available for the US (*e.g.,* "Billion ton study", US DoE (2011b)), Batidzirai, Smeets and Faaij (2012) estimated the biomass supply potential for the US for 2030 at 9.4-23.5 EJ. About 3.5-8.9 EJ (about 37% of this total) originates from lignocellusic feedstocks. The US has large biomass resources, some of which are underutilised such as mill and crop residues. Potentials of forestry and agricultural residues are 2.3-4.1 EJ and 3.4-9.7 EJ, respectively (about 60% of the total). The contribution of first generation crops is small, amounting to 0.2-0.8 EJ (3% of the total).

IRENA has conducted a biomass supply analysis (2014c) for the US and has come to a similar result for the high supply potential, but with more lower end supply potential (see Table 3). According to this analysis, which estimates the biomass supply potential of seven different biomass types for more than 100 countries, the lower end of the supply potential for the US could be approximately 18.9 EJ by 2030. The higher end is estimated at 22.7 EJ, including 7.5 EJ of biomass crops on surplus agricultural land or wood/grasses crop potential on marginal land; an additional 7.2-7.4 EJ of forestry residue biomass resulting from logging/forest thinning operations; agricultural crop residues as well as food and animal waste up to 7.8 EJ by 2030. Total biomass supply potential in the US is about 15-20% of the total global biomass supply potential of 95-145 EJ (IRENA, 2014c). If all the US biomass supply potential was to be deployed, about 20% of the US total primary energy supply today would be provided by bioenergy.

Table 3: Breakdown of total biomass supply in 2030

	2030 (EJ/year)
Forest products incl. residues	7.2-7.4
Agricultural residues incl. animal waste	5.1-7.8
Energy crops	6.6-7.5
Total supply potential	18.9-22.7

Source: IRENA (2014c)

The US bioenergy resources accounts for around a fifth of the world resource potential and equals nearly a quarter of the national energy use

The price of biomass depends on the resource type, where resource is located, where it is delivered and in which form it is transported.

Based on an EPA report published in September 2007 (EPA, 2007), prices of primary mill residues, forest residues and urban wood waste were among the lowest in the US, ranging from 0.2 to 2.7 USD per GJ. In 2010, delivered sawdust costs reached nearly USD 4 per GJ (Sikkema *et al.*, 2011).

In the Southeast US, wood pellet prices reached USD 9.5 per GJ in 2010 due mainly to tight feedstock supplies that pushed up pellet production costs (Sikkema *et al.*, 2011). Including VAT, wood pellet prices were about USD 14.3 per GJ in 2010 (Goh *et al.*, 2013). With financial support for all kinds of feedstock bioenergy from the US government, pellet production costs are expected to go down by about USD 1 per GJ. In 2012, wood pellet prices decreased to USD 8 per GJ (Hoefnagels, 2014).

According to the EPA report (EPA, 2007), landfill gas and food waste gas prices were between USD 1 and 3 per GJ. The price of agricultural residues (mainly corn stover) ranged between 3.5 and 4.2 per GJ. The prices of forest thinning were the highest, ranging between 5.5 and 9 USD per GJ (delivered costs). More data on the prices of biomass are provided in WGA (2008) and US DoE (2011b).

According to a study which estimates the supply costs of corn stover and switchgrass in the US, corn stover supply costs would range from USD 2.35 to 2.8 per GJ and switchgrass from USD 3.6 to 4.1 per GJ (compared to the coal market price of USD 34.3 per ton, or around USD 1.3 per GJ, in January 2008). These ranges are explained by the differences in the transport distances. Increasing the one-way transportation distance from 5 miles to 50 miles adds about USD 0.5 per GJ (Brechbill and Tyner, 2008).

Different types of biomass are located in different parts of the US. Depending on the market, location of demand could be distributed evenly across the country (*e.g.,* transport fuels), or could be concentrated in specific regions (*e.g.,* pulp and paper sector). Logistics (depending on the type of feedstock) could increase the supply costs of biomass, given that distances between supply and demand sources in the US could be long. Deployment of pre-processing technologies, including torrefaction, pelletisation, and pyrolysis, gain importance as they would increase the energy density of biomass which in turn could reduce transportation cost by more than half (IRENA, 2014c).

In addition, to costs of logistics, predicting the future prices of biomass is challenging. Seasonal and weather conditions (affecting yields), increased demand for different bioenergy types from different markets (paper, power, fuels, etc) as well as the complex relationship with food production all have impacts on the prices of biomass. In view of these uncertainties, cost-competitiveness of biomass relative to conventional fuels is sensitive and can change easily, which should be considered when designing new bioenergy policies.

Biomass supply costs vary from USD 1 to more than 10 per GJ depending on the type of biomass. As supply and demand are not in close proximity, transportation of biomass over long distances will raise these costs as bioenergy use increases

7 REMAP OPTIONS

Key points

- Options have been identified that could raise US renewable energy use in TFEC from around 5 EJ in 2010 to over 18 EJ by 2030 (an increase from 7.5% to 27%). REmap Options are evenly split between renewable power and renewable heat applications (incl. liquid biofuels).
- Wind and biomass would account for nearly three-quarters of the total renewable energy use in REmap 2030. For over two thirds of the REmap Options that have been identified in the power sector is related to wind. The remainder of REmap Options is equally divided between biomass, solar and geothermal.
- Wind capacity would increase six-fold from today.
- Total biomass use would increase three-fold from today. Biomass would account for more than half of the total renewable energy use in TFEC.
- Additional biomass use potential is concentrated in heating markets (buildings and industry).
- IRENA cost projections for solar PV and CSP are lower than those of EIA and NREL.
- The total package identified reduces average energy costs by USD 0.9 per GJ for consumers or it raises cost by USD 2.0 per GJ for society (USD 10 bln savings to USD 20 bln/year additional cost).
- Cost are outweighed by estimated savings due to external effects including avoided negative health effects and a reduction of 1,700 Mt of CO_2 per year in 2030.
- There are challenges for wind and biomass related to connecting supply and demand, and costs associated with these as well as institutional and regulatory barriers.

The REmap analysis for the US utilises an internally developed REmap tool that incorporates the EIA's Reference Case for 2020 and 2030 (*i.e.,* business as usual), allows for localised commodity and fuel price inputs, as well as localised renewable and conventional technology cost and performance characteristic inputs. The data, assumptions and approach used have been summarised above in Section 4. The tool then allows IRENA to enter additional renewable energy options in the end-use sectors of industry, buildings, and transport, as well as for power and district heat generation.

The process for using the tool and creating the REmap Options is as follows:

1) First, a Reference Case for 2020 and 2030 was created. This was based on the 2010 IEA extended energy balance and subsequently IEA data was updated based on the EIA's AEO 2013 (with 2010 being the base year). The Reference case for the period between 2010 and 2030 was estimated based on EIA projections. The results of this projection were explained in Section 4.
2) Second, commodities and fuel prices were localised based on projections provided by the EIA AEO both for 2020 and 2030.
3) Third, technology cost and performance criteria (*e.g.,* capacity factors) were localised based on studies provided by the EIA AEO, NREL, including the Renewable Electricity Futures Study and Transportation Energy Futures Study, and IRENA's own estimates.
4) Lastly, additional renewable energy options for all end-use sectors and the power sector were analysed based on various studies and assessment and entered into the tool.

The US has a very high potential of renewable energy utilisation because of its large size and diverse geography with strong resource intensity in many areas. The following studies have been used to identify additional renewable energy options beyond the Reference Case:

a. For the power sector, the NREL Renewable Electricity Futures Study (80% RE-ETI scenario) was used[12] (NREL, 2012a); no early retirement of power plants was considered.
b. For transport, the NREL Transportation Energy Futures (TEF) study (NREL, 2013) was used[13]. The

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[12] The study assumes different energy efficiency improvement rates and electricity consumption totals than the 2012 AEO.

[13] The study assumes a different fossil fuel consumption projection than the AEO.

TEF scenario from the Buildings Industry Transportation Electricity Scenarios[14] (BITES) tool was used which includes biofuel, with limited electro mobility and hydrogen fuel-cell deployment.

c. For the industry sector, a recent IRENA renewable energy in industry roadmap (IRENA, 2014b) and its accompanying data was used; only renewable energy options for new capacity were considered.

d. For buildings, an internal analysis of Reference Case developments and realisable potential was done. Energy consumption in the buildings sector is expected to decline slightly over the period, despite growth in total floor space. For new construction occurring over that time, varying levels of renewable energy penetration were considered. For existing building stock a system retrofit rate of 20% a decade was considered with partial substitution of fossil heat and cooling options with renewables. Buildings undergoing significant retrofits assume renewable energy deployment consistent with the implementation of a code similar to Standard 189.1 of the International Building Code for the US building stock. These assumptions result in a renewable technology penetration rate of between 16-20% of installed capacity in the building sector.

This section is divided into five sub-sections. Section 7.1 focuses on the potentials of different renewable energy technologies in the US and also mentions the top regions with resource availability. Section 7.2 provides the REmap Options. In Section 7.3, costs of REmap Options are estimated and Section 7.4 presents the cost-supply curves for the REmap Options. Section 7.5 discusses these findings.

7.1 Renewable energy technologies

Wind

The potential of wind in the US mainly lies in the centre of the country (the Midwest) stretching from Canada to Texas (see Annex E for resource map). In this region, wind speeds routinely average 8.5 meter per second at 80 meter height. This leads to capacity factors for onshore wind of as high as 40% or even more. The ability to deliver electricity to consumers from these high resource areas which are often far from consumption centres can prove a challenge given existing grid infrastructure. For this reason, in the analysis wind deployment has been broken down into two wind resource categories, one with high resource (70% of capacity additions) and another with moderate wind resource (30% of capacity additions) representative of regions closer to the eastern US load centres. Capacity factor for the high wind regions is assumed to be 42% by 2030, and 30% for the low-speed wind regions. A total of 290 GW_e of additional wind capacity is assumed over the REmap period (on top of the 63 GW_e in the Reference Case in 2030). Onshore wind will increase to 314 GW_e in REmap. For offshore wind, an additional 40 GW_e is assumed over the period on top of the 2 GW_e in the reference case. Total offshore and onshore will total 356 GW_e. This growth is based on NREL results assuming 290 GW_e (of which 11 GW_e is wind offshore) by 2030 and also includes additional wind capacity of around 65 GW_e (30 GW_e of which is offshore wind) due to increases in electrification in the end-use sectors identified in the REmap analysis. The result is total wind capacity of around 356 GW_e (42 GW_e offshore). In order to meet the increases that were analyzed by NREL, around 13 GW_e/year of newly installed capacity need to be installed, to meet the increased electrification needs identified in REmap in the end-use sectors, and additional 3 GW_e/year would be required, in total around 16 GW_e/year of additional onshore/offshore wind would need to be installed. This is higher than the US Wind Vision scenario which suggests that 10% of the US electricity demand would be supplied by wind by 2020, 20% by 2035 and 35% by 2050. This requires a growth in installed capacity of around 10 GW/year in the near term realising a total installed capacity of 210-230 GW_e by 2030 (US DoE, 2014a).

Solar PV/CSP

In the west/southwest solar irradiance levels of +5 kWh/m^2/day (see Annex E for resource map) result in capacity factor of over 22% for some utility based PV projects. The solar resource in the US differs significantly between regions so a differentiation was made for the REmap analysis between two areas: solar PV systems in high (Southwest/West US, representing 50% capacity additions) and lower solar irradiance (South/Midwest/Northeast US, representing 50% capacity additions) regions, the latter with a capacity factor of 18%. Capacity factors for solar PV for residential applications are

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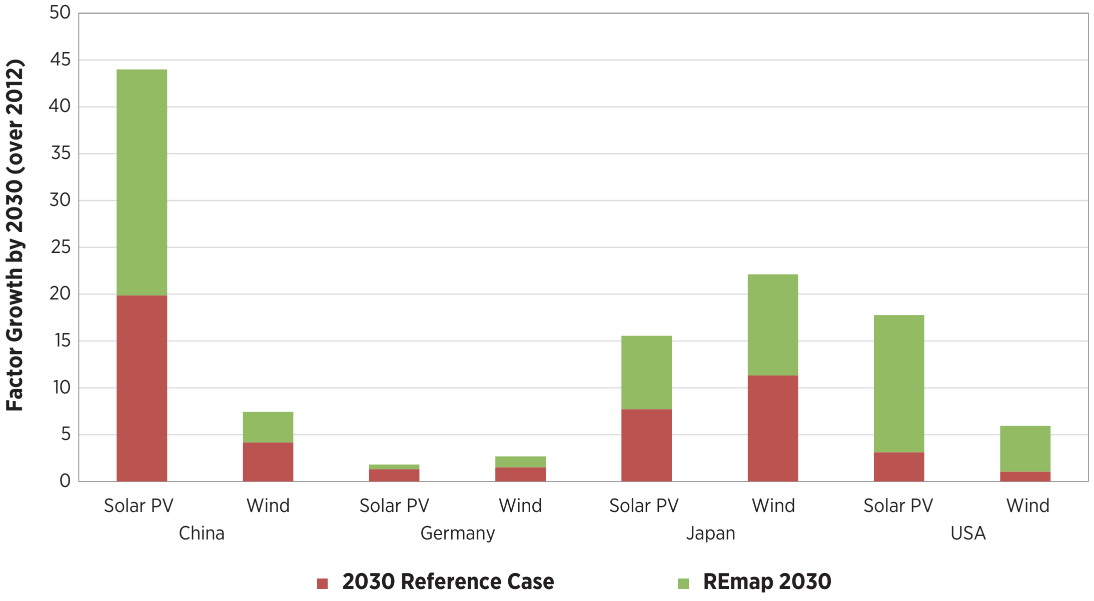
[14] The study is available at *https://bites.nrel.gov/scenarios.php.*

Figure 18: Factor increase in power capacity over 2012 for solar PV and wind for 2030, reference case and REmap



17% and 14%, respectively. An additional 110 GW_e in the 2010-2030 period (on top of the 24 GW_e in the Reference Case in 2030) was assumed in REmap 2030. This includes an additional 73 GW_e as analyzed by the NREL study, plus an additional 38 GW_e to meet electrification needs in the end-use sectors identified in the REmap analysis. In total by 2030, 135 GW_e of solar PV would be installed, representing an installation rate of around 7 GW_e per year. This growth is similar to experiences in China, Germany and Japan showing that more growth in solar PV in the US seems possible (see Figure 18).

CSP also plays an important role in certain regions of the US, particularly the Southwest where it also has high potential. An additional 1.4 GW_e on top of the 1 GW_e in the Reference Case has been assumed.

Geothermal

The US also has some of the best geothermal potential in the world. Primarily centred on the western region, deep enhanced geothermal systems can provide a geothermal resource exceeding 150° Celsius (203° Fahrenheit) (see Annex E for map). Additionally geothermal heat pumps can be used in buildings and industry for low temperature heat. In the power sector, an additional 18 GW_e has been assumed on top of the 6 GW_e present in the Reference Case. 210 PJ of additional heat provided by geothermal heat pumps has been assumed.

Biomass/biogas

As discussed earlier in Section 6, the US has substantial biomass potential in the form of crop, forest and mill residues, and still unrealised waste and landfill methane emissions potential. The US already produces significant amount of biofuels from crops, and the potential with new processes to produce advanced bioethanol from agricultural waste, or other cellulosic feedstocks is high. Primary biomass potential used either in power generation or for heat production is also substantial and currently underutilised (see maps in Annex E). The regions with the most potential are in the Midwest for crops, and the West/South for forest residues. An additional 52 GW_e of biomass power generation (including CHP used in industry) has been assumed on top of the 24 GW_e present in the Reference Case, and an additional 3.5 EJ of solid biomass use in industry and buildings has been assumed on top of the 2.5 EJ in place in the Reference Case. Similarly, an additional 1.6 EJ of liquid biofuels have been assumed on top of the 1.6 EJ in the Reference Case. With new regulations addressing the coal-based power generation, biomass co-firing (especially with wood pellets) is expected to gain a larger market share (Goh *et al.*, 2013).

Figure 19 shows total primary bioenergy demand based on REmap 2030 reaches 15.7 EJ per year, which based on IRENA's estimates would represent between 70% and 85% of the total supply potential. Almost 40% would be consumed for the production of biofuels. This would be followed by the demand in industry.

Total biomass demand in REmap 2030 would require 70-85% of the total supply potential with 40% of the total demand estimated for the transport sector

Hydro/Marine Hydrokinetic

Hydropower in the US is currently the largest source the renewable power generation; however it is expected to be overtaken by wind power due to limited new realisable potential of large scale hydroelectric power plants. Additional potential was assumed to include mainly retrofitting and upgrading turbines at existing dams, the addition of power generation facilities at non-powered dams, and some new run-of-river hydro projects. The Reference Case assumes a total hydro capacity of 79 GW_e, and an additional 35 GW_e has been included under the REmap Options (capacity factor 44%).

According to an assessment by US DoE of every two-mile stream segment for its potential to deploy small scale hydropower across the US, there are more than 500,000 viable sites where small scale hydropower can be deployed to produce more than 100 GW_e power (Kosnik, 2010).

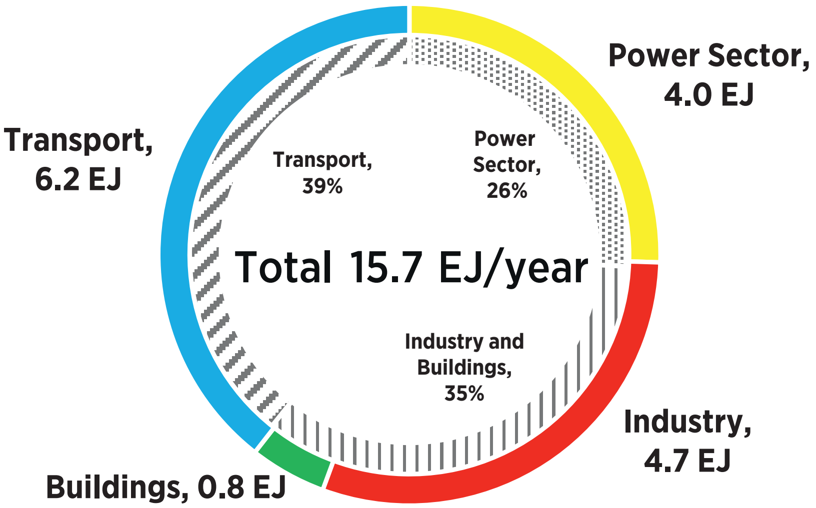
The US has ocean potential along all its coastlines, but in particular along the western coast ranging from northern California through Washington State and towards Canada and Alaska.

Additional Potentials

The detailed results of the supply assessment for renewable power generation for the REmap Options can be found in Annex C at the end of this study.

The analysis can still be expanded to include additional renewable energy options, particularly in buildings and industry where no comprehensive accelerated renewable energy scenarios are available. In industry, retrofits

Figure 19: Primary bioenergy demand by sector with REmap Options, 2030



for biomass medium/high temperature process heat, and solar thermal and geothermal for low/medium temperature heat could be considered. In the buildings, higher retrofit rates for low temperature geothermal/aerothermal heat-pumps and solar thermal heating systems could be considered. In the transport sector, additional electromobility and modal shifts (to electric bus or rail) could be considered. And in the power sector, consideration could be made to increase the renewable energy uptake based on changes in renewable energy technology costs within the last couple of years since the NREL Renewable Electricity Futures Study was released. Additionally renewable hybrid power systems with integration with natural gas generation could be explored.

7.2 Roadmap table and implications for renewable energy

REmap results in a significant increase in the amount of renewable energy consumed in total final energy. In 2010 a little under 5,000 PJ of renewable energy was consumed in the US. Around 70% was in the form of biomass, including biofuels and biogas. The only other sizable contributions were from renewable electricity in the form of hydro and wind. In the Reference Case for 2030 an additional 2,000 PJ of renewable energy will be consumed with the largest increase in absolute terms occurring in biomass, however strong growth of over 100% increase will be seen in wind and over a 10 fold increase in solar PV. The Reference Case from the EIA AEO likely underestimates renewable energy growth in the power sector, and given recent market developments in wind and solar, it is likely that these two technologies will see significantly higher growth by 2030 under business-as-usual.

The REmap Options show that considerably more deployment of renewable energy is possible. Renewable energy in TFEC could nearly triple to 18 EJ compared to the Reference Case (6.8 EJ). Figure 20 shows the anticipated increase for each renewable energy resource. The largest growth is seen in absolute terms in biomass. Nonetheless, although biomass may still be the largest source of renewable energy in REmap 2030, wind, solar and geothermal actually show the highest growth rates.

Wind power accounts for two thirds of the REmap Options identified in the power sector. The remainder is equally divided between biomass, solar and geothermal

Total hydropower capacity increases by about 35 GW_e between 2010 and REmap 2030, from 78 GW_e to 114 GW_e. Compared to the development in hydropower

Figure 20: Increases in renewable energy consumption in TFEC by resource

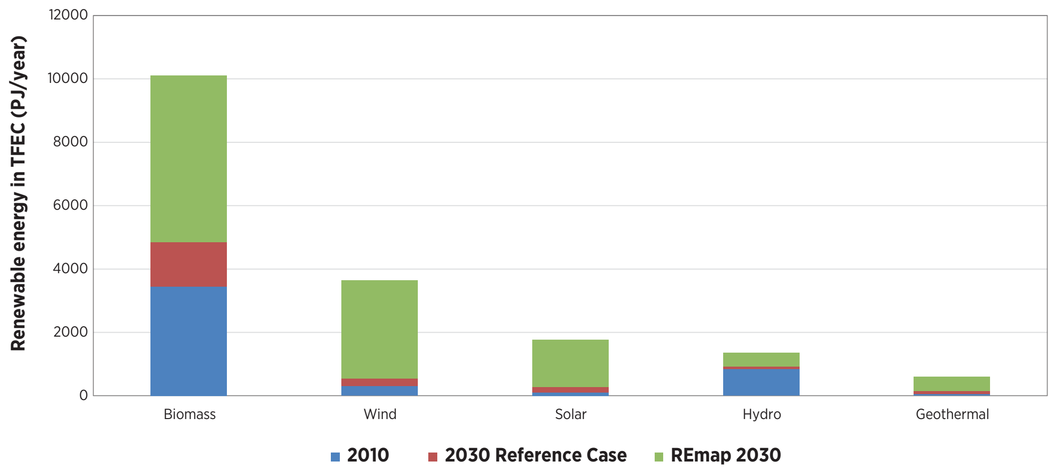


Table 4: Breakdown of renewable energy share by sector

	Renewable Share of:	as % of:	2010	2030 Reference Case	REmap 2030	RE use REmap 2030 (EJ/year)
Industry	Heat	Heat consumption	11%	13%	36%	5.3
	Heat, Electricity & DH	Sector TFEC	11%	14%	39%	7.4
Buildings	Heat	Heat consumption	6%	7%	17%	1.6
	Heat, Electricity & DH	Sector TFEC	9%	12%	34%	7.1
Transport	Fuels	Fuel consumption	4%	6%	13%	3.4
	Fuels & Electricity	Fuel TFEC	4%	6%	14%	3.6
Power		Generation	11%	16%	48%	9.0
District Heat		Generation	20%	42%	42%	0.1
Total		**TFEC**	**8%**	**10%**	**27%**	**18.1**

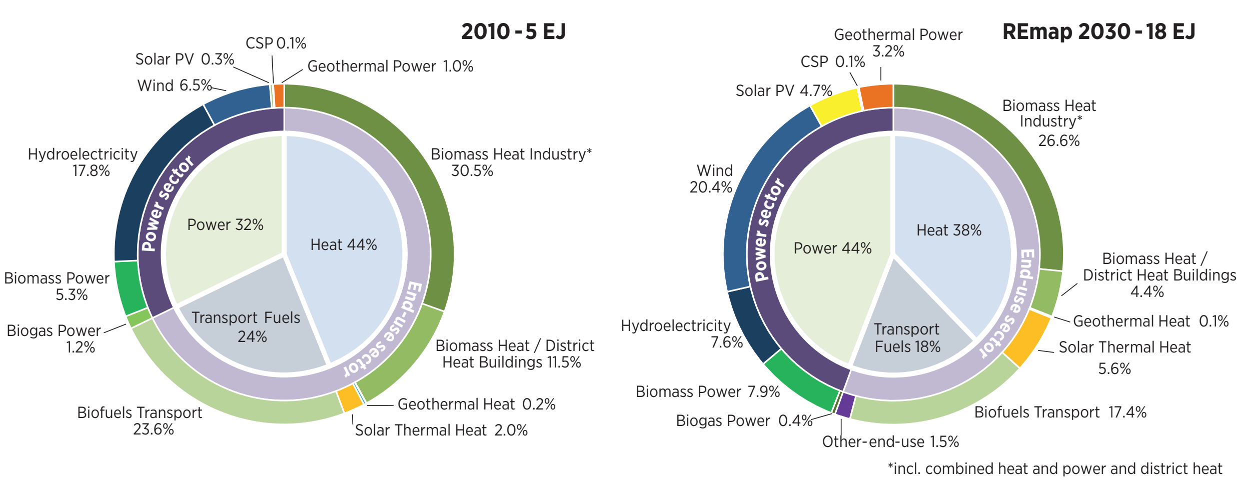
capacity between 2000 and 2010 of only few GW_e additions, this is a large increase. However this increase will include run-of-river and upgrades of current capacity with more efficient turbine systems and the powering of unpowered dams.

Table 4 and Figure 19 show the breakdown of renewable energy end use by consuming sector. Note that biomass as an energy source can be used for power, transport fuels, and heat applications biomass technologies can provide energy services in all sectors. Therefore most of the growth in biomass is therefore not in the power sector, rather in the form of biofuels and residue combustion for heating used in industry.

Options have been identified that can raise the renewable energy use in TFEC from around 5 EJ in 2010 to 18 EJ by 2030. REmap Options are evenly split between renewable power and renewable heat applications (including liquid biofuels)

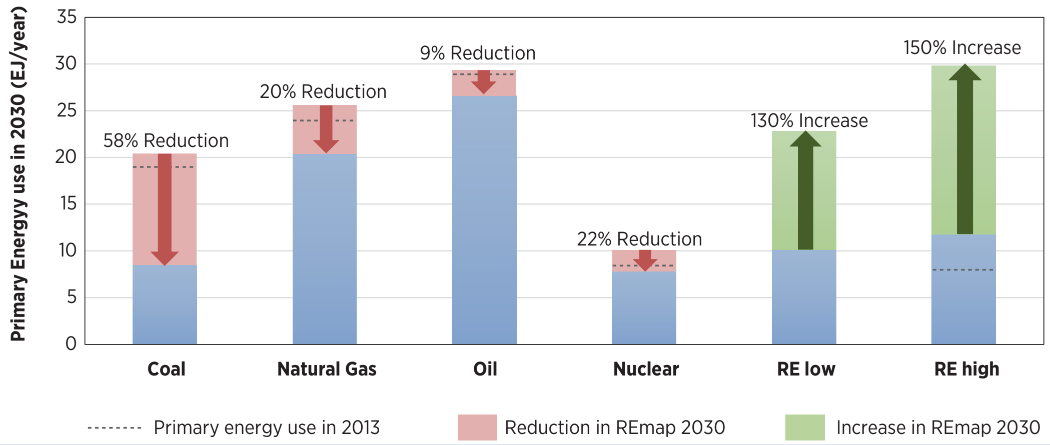
Figure 22 shows how the REmap Options would change the primary energy fuel mix in 2030, with renewable energy replacing other ("conventional") energy sources. Depending on how the conversion of renewable energy to primary energy is calculated, renewables will either become the largest or second largest contributor of energy services in total primary energy demand

Figure 21: Breakdown of renewables by application and sector in final energy, 2010 and REmap 2030



*incl. combined heat and power and district heat

Figure 22: How renewables offset fossil fuels in REmap 2030 compared to Reference Case, 2030



Note: Primary energy use for the analysis of the US is estimated based on TFEC and primary energy use in power generation; it includes energy derived from blast furnaces and coke ovens and it excludes non-energy use as well as energy for industry own-uses, for oil and gas extraction and for oil refineries.

(TPED)[15]. The renewable energy high calculation uses the EIA partial substitution method while renewable energy low calculation uses the IEA physical energy content method. These do not represent different cases, or levels of renewable energy consumption, rather differences in converting renewable electricity and heat into primary equivalents.

In primary terms renewable energy is increased between 130-150% over the 2030 Reference Case, representing a renewable energy share in TPED of 27% for “RE low” or 34% for “RE high”. Coal sees the most significant reduction with 58% fuel savings to just over 12 EJ of primary fuel to become the second lowest contributor to primary energy just above nuclear (which is presented in physical energy content terms, comparable then to renewable energy low). Natural gas sees the second largest reduction in absolute terms, however it only represents a 20% in fuel savings. Oil remains the largest, or second largest if using the substitution method, contributor of primary energy and sees only a 9% reduction.

Table 5 provides more detail about the evolution of the energy system as envisioned in this study, including 2010 (the analysis base year), 2030 Reference Case, and REmap 2030. The renewable energy share in TFEC grows from 7% in 2010 to only 11% in 2030 according to the Reference Case.

Implementing all REmap Options (see Sections 6.1-6.5) can raise the renewable energy share to 27% in REmap 2030. This will result in total renewable energy use of 18.1 EJ/year by 2030. This consists of 3.1 EJ liquid biofuels, 6.8 EJ renewables for heat in end-use sectors and 9.1 EJ renewable power generation. Electrification in end-use sectors results in additional power generation of 250 TWh/year in REmap 2030 compared to the Reference Case, *i.e.,* 7% additional electricity demand. Biofuels used in transport will total 3.2 EJ, with 40% coming from advanced biofuels.

The share of renewable power generation grows to 48% in REmap 2030. This includes 26% variable power (based on generation). Growth in the power sector’s renewable energy share is substantial compared to the Reference Case. This is mainly due to growth in wind (nearly 980 TWh), with both biomass (including biogas) and solar PV adding around 200 TWh each, followed by hydro and geothermal with around 140 TWh each. In terms of

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[15] There are different methods applied to estimate the total primary energy demand. The two applied in this study are the “physical energy content” and “substitution” methods. The physical energy content method is used by the IEA and Eurostat where renewable electricity and biofuels are counted as primary energy as they appear in the form of secondary energy, while geothermal, CSP and nuclear are counted using average process efficiencies to convert them into primary energy equivalents. The substitution method is used by the US EIA and BP where renewable electricity and heat are converted into primary energy using the average efficiency of the fossil fuel power and heat plants which would otherwise be required to produce these quantities.

Table 5: US REmap 2030 Overview

1. Electricity generation		**Unit**	**2010**	**Reference Case 2030**	**REmap 2030**
Power Capacity	Hydropower (excl. pumpyed hydro)	GW_e	78	80	114
	Wind Onshore	GW_e	39	61[1]	314
	Wind Offshore	GW_e	0	2	42
	Biomass (incl. CHP)	GW_e	9	24	76
	Biogas	GW_e	3	8	8
	Solar PV	GW_e	2	24	135
	Solar CSP	GW_e	0.5	1	2.5
	Geothermal	GW_e	2.5	6	24
Electricity Generation	Hydropower	TWh	260	294	430
	Wind	TWh	96	174	1 154
	Biomass	TWh	76	238	490
	Biogas	TWh	19	22	22
	Solar PV	TWh	4	43	235
	Solar CSP	TWh	1	3	8
	Geothermal	TWh	15	43	183
2. Heat Supply					
Solar water heater / cooling		PJ	96	126	996
Geothermal energy for heating		PJ	11	22	25
Biomass residential		PJ	576	602	779
Biomass industrial		PJ	1 529	2 060	5 077
Total		PJ	2 212	2 810	6 877
3. Vehicle					
Electric vehicles (EV, PHEV)		Mln	0	1	27
Electric vehicles		TWh	0	5	147
Biofuels		PJ	1 196	1 567	3 108
4. Ratio of electricity generation					
Gross power generation		TWh	4 129	4 868	5 224
Generation ratio of renewables		%	11%	16%	48%
5. Ratio of Total Final Energy Consumption					
TFEC		PJ	64 150	66 678	65 688
Renewable gas, heat and fuel		PJ	3 410	4 478	9 985
All renewable energy[1]		PJ	5 105	6 812	18 100
Ratio-renewables to TFEC		%	7.5%	10.2%	27.5%
6. Ratio of Total Primary Energy Demand					
Total TPED – Partial substitution method		PJ	89 900	95 100	88 400
Renewable primary fuels or equivalent		PJ	7 700	11 800	29 800
Ratio-renewable to TPED		%	8.6%	12.4%	33.7%
Total TPED – Physical energy content method		PJ	90 300	95 550	86 124
Renewable primary fuels or equivalent		PJ	6 130	10 120	22 900
Ratio-renewable to TPED		%	6.8%	10.6%	26.6%

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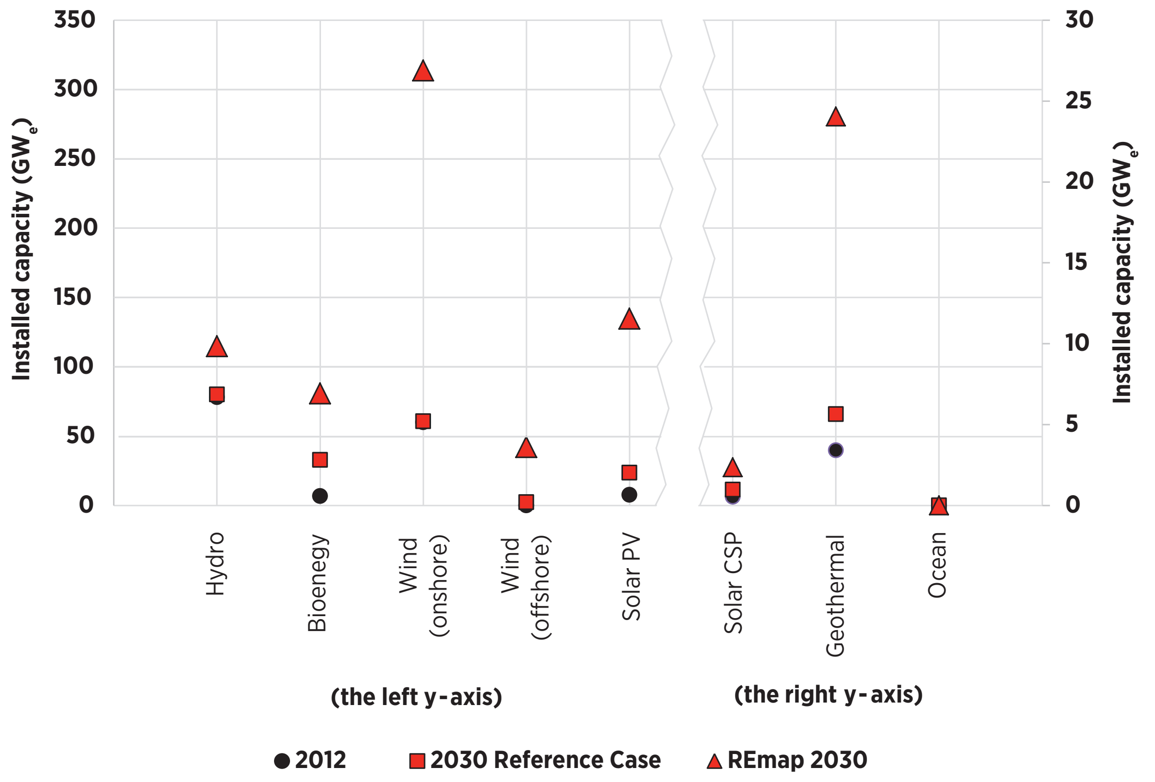
[1] *Based on US EIA AEO 2013; the AEO 2014 has revised up the reference case to 77 GWe, however only after the preparation of this analysis. This includes 14 GWe of wind projects under construction as of second quarter of 2014, but the additional estimated 26 GWe is in planning stages is excluded from the AEO 2014 projections.*

Figure 23: Power capacity by renewable energy technology



capacity, wind increases by almost six fold to 365 GW (incl. 42 GW$_e$ offshore) in REmap 2030 compared to 63 GW$_e$ in Reference Case (see note 2 in Table 5). This increase is also being driven by increased electrification in the end-use sectors, which is supplied with renewable electricity coming from wind (70%) and solar PV (30%). It is mainly coal capacity that is being replaced; there is 189 GW$_e$ less coal capacity in REmap 2030. For more detail see the summary tables in Annex F.

Wind power accounts for almost two thirds of the REmap Options that has been identified in the power sector. The remainder is divided between biomass, solar and geothermal

Figure 23 provides an overview of capacity developments based on the REmap options. Wind, solar PV and geothermal offer the greatest growth in capacity terms, with growth potential in REmap 2030 around five times greater than the projected capacity in 2030 according to the Reference Case.

The renewable energy share ranges between 13 and 39% in end-use sectors. This growth is mainly from biomass. Primary biomass demand in the US nearly triples from 6 EJ in 2010 to more than 16 EJ in REmap 2030 if all REmap Options are deployed (demand in all sectors). About three-quarters of this total is demand from the end-use sectors. 6.2 EJ is required as raw biomass for the production of liquid biofuels of 3.1 EJ (based on a 50% conversion efficiency of raw biomass to final product). 5.1 EJ is demand for industrial process heat generation. 0.8 EJ is required for heating in the building sector. The remainder 4 EJ is demand for power generation in industrial CHP plants and power-alone main activity plants. Total biomass demand would be 70-85% of the total biomass supply potential of 19-22.7 EJ (IRENA, 2014c). This outcome indicates that raising the renewable energy share in the US will require the deployment of a substantial amount of its domestic biomass resources. Moreover as the US continues to be an exporter of various bioenergy commodities, utilisation may well reach the limits of supply and raise the cost.

Total biomass use would increase three-fold from today. Biomass would account for more than half of the total renewable energy use in TFEC

The contribution of non-biomass renewable energy technologies to heat supply in the building and industry sectors is relatively lower, solar thermal at 1 EJ and geothermal at 0.4 EJ. Although their contribution is less, the growth in capacity for both is substantial. Solar thermal grows by a factor 10 and geothermal grows by a factor 40 between 2010 and 2030. Solar thermal capacity in 2030 would reach more than 310 GW_{th} (or 450 million square meters). This is as much as the solar thermal capacity installed worldwide today.

The number of EVs increases to 1 million per year only in Reference Case by 2030. According to REmap Options, the total number can be increased by another 26 million in the same year, to a total of 27 million vehicles on the road. Of this total 21 million will be PHEVs, and 6 million being all electric. The amount of additional electricity needed to power these vehicles would total almost 150 TWh per year – 60% of the additional 250 TWh of power demand resulting from electrification. It is assumed that this demand will be met by renewable power sources.

7.3 Renewable energy technology cost projections

Table 6 provides an overview of current and projected LCOE for new capacity plants LCOE of existing plants are excluded from this figure[16]). Both the EIA and a summary of LCOE projections completed by NREL project that natural gas combined-cycle generation will decline from around an USD 70 per MWh from 2008-2012 to between USD 55-65 per MWh in 2020 and 2030 (see also Box 1). However it is assumed that REmap Options will not substitute natural gas based generation, rather a portfolio representing advance coal and nuclear, both of which are projected to remain around USD 95 per MWh according to the EIA.

According to EIA, NREL or IRENA projections, many renewable energy technologies will be able to compete based on LCOE with advanced coal and nuclear power by 2030, if not sooner. Renewable energy technologies such as onshore wind and solar PV (utility) are projected even to compete with natural gas based generation (these estimates do not include any subsidies). In 2030, utility scale solar PV could be the cheapest, followed by wind onshore with high wind resource and natural gas. However, it should be noted that costs related to the integration of variable renewable are outside the scope of this study, and according to the IEA this could add between USD 5 and USD 25 per MWh (IEA, 2014). These additional costs, depending on whether they are on the low or high end, could have an effect on the ranking of power generation costs. It should also be noted, however, that rooftop solar PV is one of the only technologies that can produce electricity directly at points of consumption, so a comparison with wholesale power costs are not appropriate. Rather if viewed from a "plug-parity perspective" *i.e.,* against the price of retail electricity, rooftop solar PV costs are around USD 0.09 per kWh, which provides a saving when compared to retail rate of USD 0.11-0.15 per kWh. It shows that solar PV, wind onshore (both high and low resource) and landfill gas also result in cost savings.

By 2030 onshore wind and utility scale solar PV will be the cheapest power generation options

In the buildings and industry sectors, the outlook is more challenging for renewable energy technologies. (See Annex D for an overview of these sector end-use costs). Due to the increased supply of domestic natural gas, and a continued low price of both household and industry natural gas, many types of renewable energy technologies that provide space heating, or process heat, will find it hard to compete based on price alone.. Exceptions may be made where solar cooling technologies or heat pumps can replace air conditioning (particularly important during times of peak demand), areas where a high solar resource can take advantage of solar heating, or where biomass supply is ample and can provide co-generation of heat and power.

In the transport sector the outlook for renewable energy is strong. Since US oil is a benchmark for international crude oil pricing, the price per barrel in the US does not deviate much from the increases seen around the world. The EIA projects the price to increase to USD 138 per barrel by 2030, which translates to a price for pet-

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[16] REmap substitution does not require early retirement of capital stock, so comparisons of cost to existing plants is not made.

Table 6: Comparison of LCOE for power sector technologies

	2008-2012[1] (USD/MWh)	IRENA 2013[2] (USD/MWh)	EIA 2019[3] (USD/MWh)	NREL 2030[4] (USD/MWh)	REmap 2030[5] (USD/MWh)
Renewables:					
Hydro, run-of-river	90	20-105	85		85-103
Wind onshore	70	80	80	59	50-60
Wind onshore, low wind resource					70-84
Wind offshore	160		204	77	95-120
Solar PV (Rooftop)	330	60-250	130	222	85-100
Solar PV (Utility)					45-55
Solar PV (Rooftop), low solar irradiance					93-126
Solar PV (Utility), low solar irradiance					55-66
Solar CSP PT storage	210	170-370	243	146	90-123
Biomass steam cycle	80	50-105	103	74	145-165
Landfill gas ICE					50-60
Geothermal	60	58-120	48	82	85-100
Conventional:					
Coal, US weighted cost					95
Nuclear, US weighted cost					90
Coal (pulverised, scrubbed)	90		96	56	
Coal – IGCC			116	60	
Coal – IGCC with CCS			147		
Natural Gas (combined cycle)	70		66	56	
Natural Gas – with CCS			91		
Nuclear	340		96	68[6]	

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[1] NREL Transparent cost database, average 2008-2012, http://en.openei.org/apps/TCDB/. Assumes a discount rate of 7%.

[2] Assumes a discount rate of 10%.

[3] http://www.eia.gov/forecasts/aeo/electricity_generation.cfm (2014 estimates). Assumes a real after tax weighted average cost of capital of 6.5%

[4] Page 38 http://www.nrel.gov/docs/fy11osti/48595.pdf (converted to 2010 USD with 5% inflation), average of 6 projections, all projections made around 2009 for 2030 and some, such as solar PV, are outdated. Assumes a discount rate of 7%.

[5] Assumes a national discount rate of 7%.

[6] NREL assumes that starting in about 2015, based on the AEO data set nuclear capital costs start to decline in over time, with projected costs falling below USD 2,500 per KWh by 2030.

rol increasing from USD 23 in 2010 to USD 32 USD per GJ in 2030 (USD 3.02 – 4.22 per gallon) – an increase of around 50% assuming no increases in the gasoline (petrol) tax. The price pressure that this will bring to petroleum based transport will enable many types of alternative transport technologies or fuels to compete on a cost-basis. However, because many alternatives exist ranging from biofuels (conventional and advanced), to hydrogen, biomethane, electromobility, and because there are infrastructure costs associated with increased uptake, the cost structure of these technologies are still hard to estimate. What is clear, however, is that most of these technologies pose realistic potential to compete with gasoline (petrol) use in transport on a cost-basis according to the methodology applied and the cost data (capital and operation and maintenance (O&M)

costs, energy prices and discount rates) used in this study.

7.4 Summary of REmap Options: cost-supply curves

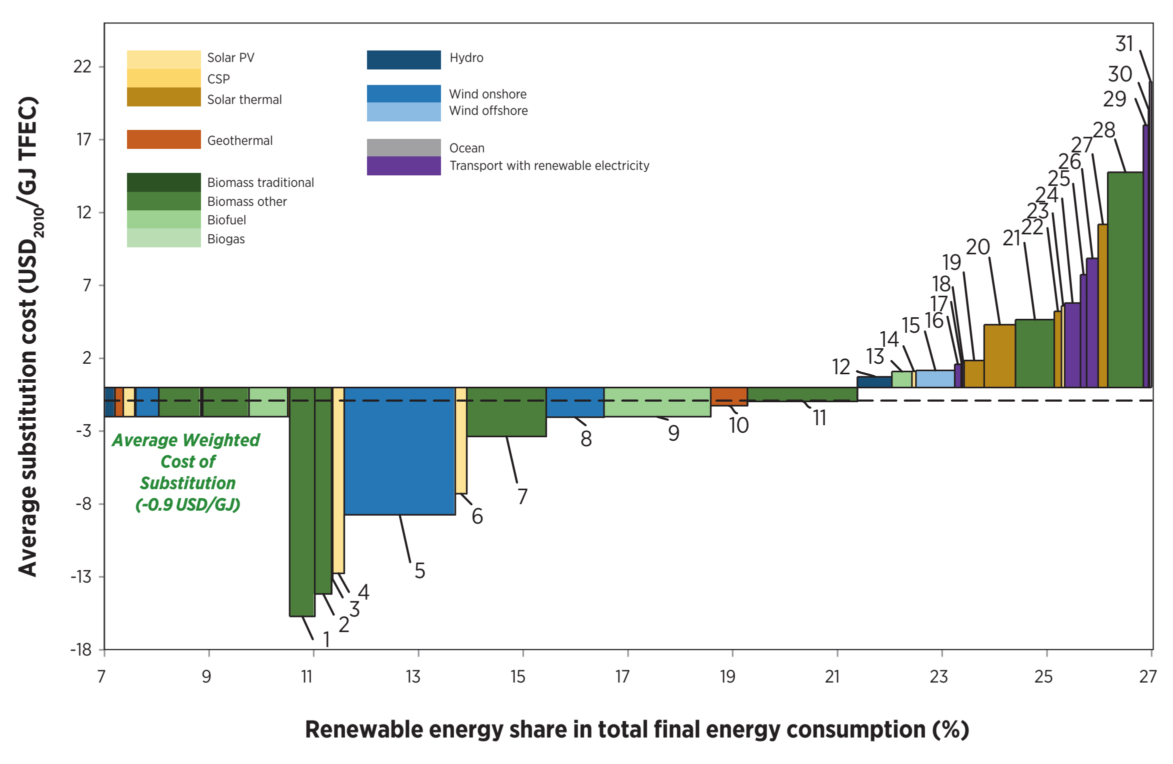
The previous sections have discussed the technology options and the technology cost. In this section, the options are aggregated into an overall potential curve, and they are ranked in terms of their cost effectiveness.

The cost-supply curve displays an approximate representation for the realistic potential of renewable energy technologies – the REmap Options – which can be deployed by 2030 on top of the Reference Case. The cost supply curve is not used to develop the REmap 2030, but it is a representation of the REmap Options which have been selected.

The REmap Options are a portfolio of technologies of accelerated renewable energy deployment in the power, district heat, and end-use sectors of buildings, industry and transport. This portfolio is not an allocation of the global additional potential based on the GDP of the US and the other 25 REmap countries, nor does it represent extrapolations. Further technology portfolios can be generated based on the different understanding of the parameters that constitute REmap Options or other studies looking at the specific case of the US.

The results of the analysis are shown in the cost-supply curves in Figure 24 through Figure 27. This includes

Figure 24: REmap Options cost supply curve, business perspective, by resource



See Annex C for the numbered technologies.

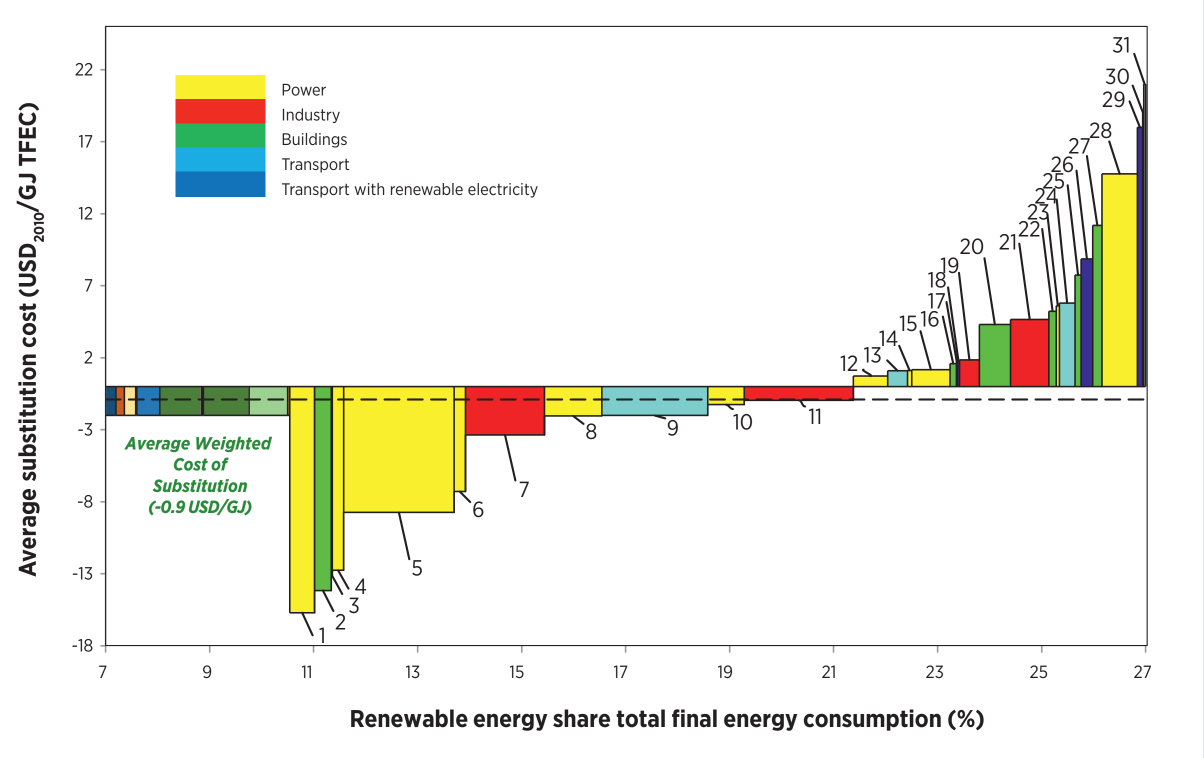
Note: The purple bars represent electrification technologies. The substitution costs of these technologies include their annualised capital (e.g., EV ownership cost), O&M and energy costs vs those of their conventional counterparts (e.g., ICE passenger car running with gasoline). It is also assumed that each additional electrification technology will result in renewable power generation capacity investments; hence, it is assumed they consume electricity from renewable sources only. These costs are included via the electricity prices that account for the changes in the US power generation mix. As opposed to depicting the energy demand technologies (e.g., EV, heat pumps), bars for electrification technologies could also be represented by the renewable electricity supply technologies which consists of 70% wind and 30% solar PV in the case of the US.

two sets of curves: one based on local costs (business perspective) that incorporate the local cost of capital (7% discount rate), commodity prices that include local taxes or subsidies, and technology cost and performance characteristics; and another (government perspective) based on standard international commodities costs (with differentiation made for coal and natural gas between export and import countries) and a fixed 10% discount rate. The former reflects factors likely to influence private investment decisions; the latter with factors more relevant to government decisions on policy and spending. Each of these two curves is presented twice, once colored by resource and once by sector. The localised cost supply curves are used to examine the economic cost and financial savings potential of increased renewable energy uptake, the standard international curve is used when considering R&D needs, comparing renewable potential and costs across regions or globally and it also provides insight into cost differences between the US and global markets resulting from policy decisions such as energy taxation.

Decision makers will be tempted to pick low-cost options, from the left end of the curve, and to skip high-cost options on the right side; however the figure gives a perspective of the entire country. Decision makers may assume that options represented by individual blocks in the supply curve are homogenous in terms of substitution costs. However, the blocks represent averages based on the assumed deployments in the REmap 2030. The cost curve should not be misinterpreted as a series of steps from left to right, in order of costs that can be chosen or not chosen in isolation; rather, there are synergies and interactions, and all of these options need to be exercised together to achieve this level of costs and the indicated renewable energy shares. For instance, some options produce savings or improvements in efficiency that help reduce the costs of more expensive options below those that would exist otherwise. The focus on the cheapest individual options will not result in the least expensive overall transition; achieving that requires a holistic approach, and only when all of these options are pursued simultaneously can the share of renewables in TFEC of US be raised to 27% by 2030 according to this study.

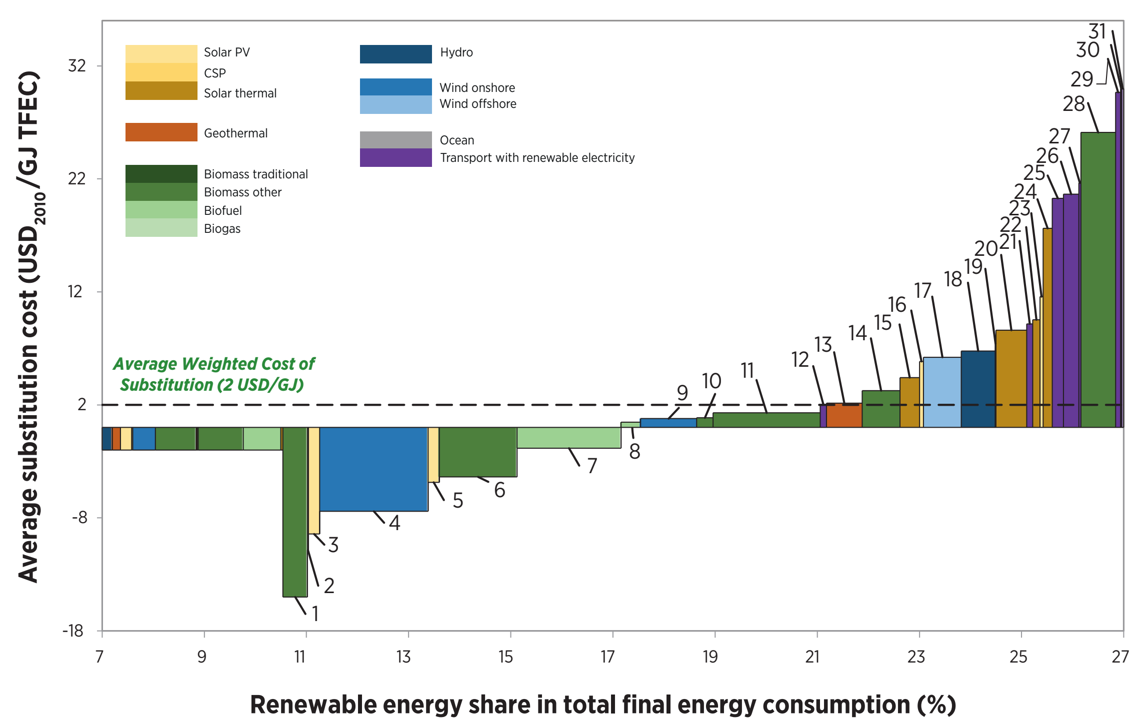
In Figure 25 the same curve is displayed but with the technologies coloured by sector. This curve shows that

Figure 25: REmap Options cost supply curve, business perspective, by sector



See Annex C for the numbered technologies.

Figure 26: REmap Options cost supply curve, government perspective, by resource



See Annex C government perspective for the numbered technologies.

the additional potential lies largely in power, industry and transportation biofuels.

Figure 26 and Figure 27 are the REmap cost-supply curves for the US based on standardised international commodity price estimates (which exclude the effects of taxation or subsidy) and a 10% discount rate. The curve is significantly different from the localised one, resulting from the changes relating to the discount rate (10% versus 7%), and higher natural gas, coal and biomass prices. In addition to showing cost differences driven by commodity prices that are locked into a local market (such as natural gas), this curve also shows the effects of price difference resulting from subsidies and taxes on energy and how they can affect technology deployment. This curve is also used to look at regional and international contexts when comparing the results from the US.

For the REmap cost-supply curves, the Reference Case growth in renewable energy from 2010-2030 is shown by first horizontal bar, which is coloured based on resource. The resource coloring is consistent with the deployment of renewable energy seen in the Reference Case. The results of the REmap analysis and accelerated deployment of renewable energy (the REmap Options) is plotted in the curve as coloured bars showing the additional potential of each technology (on the x-axis) and the average incremental cost of substitution of deploying that technology in lieu of a conventional variant (on the y-axis). The Reference Case already includes some significant expansion of renewable resources: wind and solar already see growth in the Reference Case and their incremental potential is lower in the REmap Options. In the US, renewable energy in TFEC is expected to grow from 7% in 2010 to around 10% by 2030.

The conventional variants for these REmap Options are generally petroleum (gasoline or diesel) for transport technologies and natural gas for both buildings and industry applications (with an exception for heating oil in buildings). For power production an average wholesale power production price of USD 0.09 per kWh was used, based on a weighted average as follows: 6% new nuclear, 5% advanced coal CCS, and the remaining 89% EPA compliant conventional coal[17].

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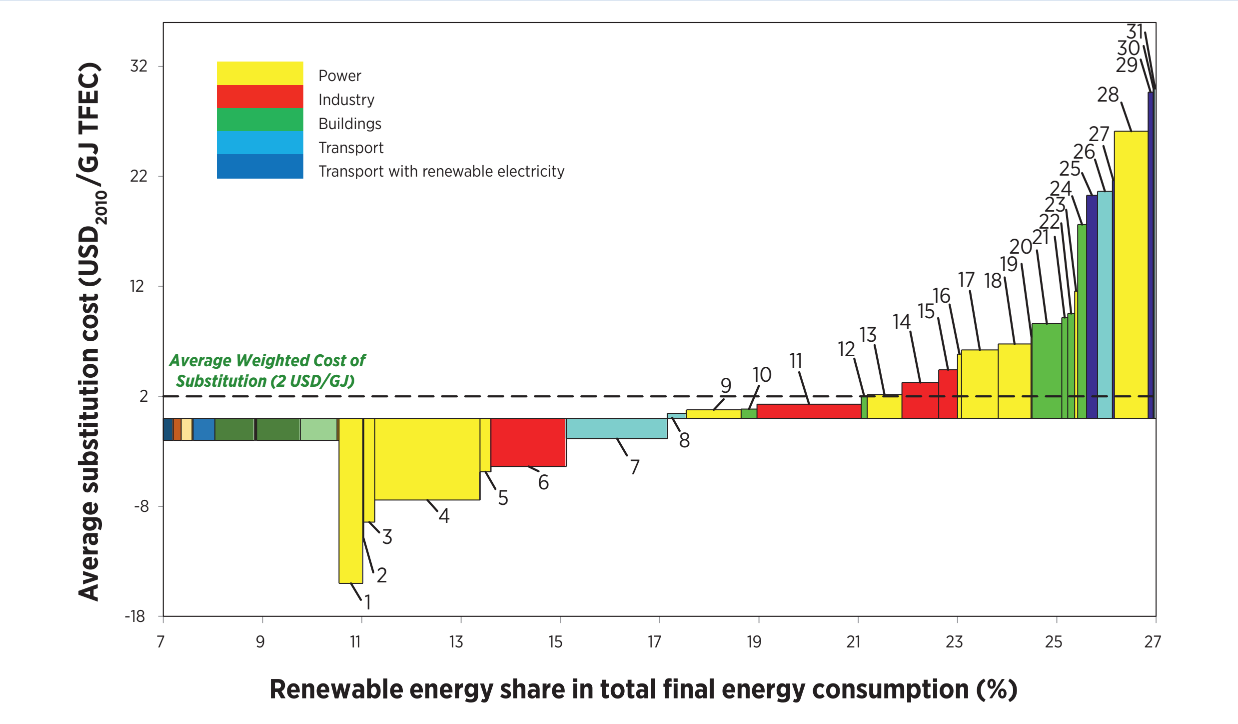
[17] Flue gas desulfurization/dry sorbent injection are required for compliance with the EPA MATS standard.

Figure 27: REmap Options cost supply curve, government perspective, by sector



See Annex C government perspective for the numbered technologies.

The total package identified reduces average energy cost by USD 0.9 per GJ for consumers

Cost-curve results by sector and technology

The results in Figure 24 are dependent on projections of technology cost and fuel prices. An overview of the assumptions underlying these projections is available in Annex A-D. The technology option mix and costs vary according to sector. Costs associated with the Reference Case are not quantified as they are part of expected energy system developments and outside the boundaries of the REmap analysis.

The results from the REmap cost-supply curves show that the majority of REmap Options identified, if viewed from a business perspective (national prices), could be deployed at a cost-savings when compared to natural gas, coal or oil alternatives (see Annex C). Table 7 shows the average cost of substitution for each sector. If viewed from a business perspective the REmap Options result in cost-savings of USD 0.9 per GJ, led by cost competitive renewables deployment in the industry and power sectors (large amount of biomass residues in industry; onshore wind, solar PV (utility), and geothermal in the power sector). If viewed from the perspective of governments (international prices), the cost of substitu-

Table 7: Overview of the average cost of substitution of REmap Options for the US

	Business Perspective (national prices) (USD/GJ)	**Government Perspective (international prices) (USD/GJ)**
Power	-2.2	1.7
Industry	-1.9	-1.2
Buildings	1.3	7.6
Transport	2.5	5.5
Average of all sectors	**-0.9**	**2.0**

tion increases to USD 2.0 per GJ, assuming the removal of tax on fossil fuels (since biomass is taxed relatively little and other renewable energy technologies that have no fuel demand are not effect by fuel taxes) and a high discount rate of 10% (most renewable energy technologies have higher capital costs).

For power generation geothermal, solar PV, wind (onshore) are all cost competitive and result in cost-savings when compared to the average weighted cost of conventional generation. Wind onshore results in cost savings in both high and low resource areas. Wind offshore results is only a slight incremental cost of USD 1.2 per GJ, similar to hydro at around USD 1 per GJ. Geothermal power is cost competitive, but only slightly with around USD 1 per GJ in cost savings. Solar PV can result in cost savings both in utility scale in both high and low resource areas, and rooftop scale is cost competitive in high resource areas and but has a low incremental cost in areas with lower solar intensity. It should be noted, however, that rooftop PV is one of the only technologies that can produce electricity directly at points of consumption, so a comparison with wholesale power costs is not appropriate. Rather if viewed from a "plug-parity perspective" *i.e.,* against the price of retail electricity, rooftop solar PV costs around USD 0.09 per kWh, which provides a saving when compared to retail rate of USD 0.11-0.15 per kWh.

In the industry sector the renewable potential is largely found in biomass and some limited solar thermal applications (compared to natural gas-fired systems). Biomass CHP results in cost-savings (USD -2.7 per GJ) when using residues as a fuel. However, direct heat applications with biomass for high-temperature process heat, results in an incremental substitution cost of around USD 6 per GJ. The deployment potential of low temperature process heat from solar thermal is limited even though it results in only slightly higher incremental costs (USD 2.6 per GJ). All renewable energy technologies in industry substituted natural gas based heating and process heat systems.

In the building sector the potential identified of REmap Options for buildings is limited, although many of the technologies are cost-competitive (compared to a mix of petroleum and natural gas heating systems). Biomass heat (pellets) is cost competitive when compared to fuel oil based heating, which is common in the northeast of the US, but not with gas. Solar cooling results in an incremental cost (USD 11 per GJ) when compared against electric cooling (air conditioners). Both geothermal and aerothermal (air-to-air) heat pumps cost slightly more (USD 1-9 per GJ) due to their high capital costs, but these technologies are significantly more energy efficient. Solar thermal heat results in only slightly higher costs (USD/GJ), even when compared to low priced natural gas.

In the transport sector biofuels remain cost competitive with a large potential of second generation bioethanol that results in cost savings. First generation bioethanol has limited potential due to increases already seen in the Reference Case and results in slight positive cost of substitution. Electromobility has significant potential, though appearing small in energy consumption terms, is actually large when based on passenger miles. This is due to the high efficiency of electricity-based vehicles relative to their petroleum-based equivalents. An electric vehicle can travel 2-3 times the distance using the same amount of energy as a gasoline vehicle where half or more of the physical energy is lost in combustion. Both electro-mobility and hydrogen fuel cells show positive costs of substitution. However this is the result of an assumption of the capital cost for these types of vehicles being higher than their conventional variants. An important note with all electrification technologies is that they shift fuel consumption to the power sector, and increases in electricity demand resulting from this shift are met with new renewable power capacity, according to the REmap methodology. The effects of a higher share of renewable power on wholesale power generation costs are taken into account.

Benefits of REmap Options

In addition to economic arguments for increased renewable energy deployment, there is also strong environmental one. In fact, environmental considerations, particularly for CO_2 mitigation, are the driving force behind government interest in RE. The REmap Options would result in an estimated reduction of 1.6 gigatonnes (Gt) of CO_2 by (Table 8) reducing emissions from over 5.5 GT to 3.9 Gt. The largest decrease would occur in the power sector where 95% of the TWh of REmap Options renewable electricity generation would replace coal-fired power. If all REmap Options were fully deployed, the US could reduce its CO_2 related emissions from energy combustion by 30% over the 2030 Reference Case. President Obama has pledged to reduce CO_2

Table 8: Development of US CO_2 emissions, 2010-2030

	2010 (Mt/year)	Reference Case 2030 (Mt/year)	REmap 2030 (Mt/year)	Total Avoided (Mt/year)
Power and district heat generation	2369	2364	1188	1176
Industry	760	867	683	185
Transport	1904	1772	1586	186
Buildings	570	544	453	92
Total emissions from fossil fuel combustion for energy services	**5604**	**5547**	**3909**	**1639**

emissions by 17% from their 2005 levels by 2020 (White House, 2013a). In 2005 CO_2 emissions from energy consumption were around 5.8 Gt, and in 1990 around 5 Gt. In REmap 2030 they would be 3.9 Gt and would therefore represent a reduction of 33% over 2005 levels, and around 22% over 1990 levels. With increased energy efficiency measures, these reductions would be even higher.

Emission intensity of the power generation mix would reach 232 grams CO_2 per kWh (g CO_2/kWh) by 2030. Compared to the Reference Case this is a reduction of more than half, and compared to 2010 level (575 g CO_2/kWh) it is approximately 60%. EPA targets a reduction of 30% compared to 2005 level (595 g CO_2/kWh) which is also met with REmap Options, but also partly from switching to less emission intensive fossil fuels in the Reference Case such as natural gas instead of coal.

There are also socio-economic benefits of increasing the share of renewables. According to IRENA's estimates, about 6.5 million people were already employed in 2013 in the renewable energy industry worldwide (IRENA, 2014e), a number which, according to REmap 2030, could reach 16 million (in cumulative job-years) by 2030. This implies an equivalent of 0.9 additional jobs which could be created in the global renewable energy sector (IRENA, 2014a). Given that a large share of the global renewable energy use estimated in 2030 would be in the US, the country can benefit from these additional jobs created.

Today, the renewable energy sector of the US employs 612,000 people. A third of this total is employed in liquid biofuel production, and one-quarter in the solid biomass sector (IRENA, 2014e). By 2010, the US wind industry employed more workers (85,000) than the coal mining industry (80,000) (NRCD, 2014). The supply chain of jobs is spread across 560 facilities in 43 states (US DoE, 2014a). Bioenergy industry in the US also contributed to the creation of many jobs. The supply chain of the ethanol industry, for example, employed in total 386,500 people in 2013. Direct (86,500) and indirect (87,000) jobs accounted for 45% of this total (ABF, 2014). US Wind Vision (US DoE, 2014a) envisages a growth in wind-related direct jobs of 233,000 and another 175,000 induced jobs by 2030.

The REmap Options identified in the US result in a small incremental cost of substitution from a government perspective. The result is an incremental system cost[18] of USD 13-20 billion in 2030 (Table 9). System cost calculations from a government perspective exclude energy taxes and subsidies, and use a standard 10% discount rate for capital investment. Incremental system cost does not include benefits related to reductions of air pollution (health) and CO_2 emissions. If such externalities are included, and depending on how these are valued, full deployment of the REmap Options could result in estimated reduced health costs of USD 10-29 billion per year by 2030. These avoided external costs result from a reduction of health complications due to air pollution from fossil power plants and fuels used in the transport sector. If the benefits of the 1.6 Gt of reduced CO_2 are taken into account, an additional USD 32-128 billion per year could be saved by 2030 (based on carbon

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18 Net incremental system costs: This is the sum of the differences between the total capital and operating expenditures of all energy technologies based on their deployment in REmap 2030 and the Reference Case in the period 2010–2030 for each year.

price of USD 20-80 per tonne CO_2)[19] The result of these externalities is a reduction in energy system cost when including the health and CO_2 benefits of between USD 29-137 billion per year. It is therefore possible to more than double the share of renewable energy from 8% to 27% by 2030 with significant in social costs savings if external costs are included, and depending on how these are valued.

Cost are outweighed by savings of external effects including 1600 Mt of CO_2 reductions per year

Table 9 shows that total investments in renewable energy technologies needed to attain the 27% renewable energy share would require USD 86 billion in investment per year, of this USD 77 billion would come from the REmap Options and USD 9 billion from investments taking place in the Reference Case. The REmap Options investment of USD 77 billion would replace an investment volume of USD 39 billion that would have been invested in convention al energy variants, therefore an incremental investment of USD 38 billion per year would be needed. The table also shows that in addition to higher investments, an annual subsidy of USD 46 billion would be required to make REmap Options with positive substitution costs "competitive" with fossil technologies. Technologies which require a subsidy lie mainly in the end-use sectors rather than in the power sector, namely for heating in buildings and industry (solar thermal) and electric vehicles. The subsidy need per MWh of final renewable energy is equivalent to USD 1.4, excluding the effect of any carbon price.

This cost would likely be borne by consumers in the form increased energy costs or by consumers as taxpayers. It is important to note that by 2030 many renewable energy technologies will not require a subsidy, and should actually result in lower energy costs, so a better metric for energy prices is the incremental system cost, which shows that energy prices would increase only very slightly. However it is important to also consider the greater economy wide benefits, which as previously discussed result in net savings by 2030 of between USD 29-137 billion per year.

Table 9: Financial indicators of REmap Options, based on government perspective

	(USD bln/year)
Changes in costs of the energy system (in 2030)	
Incremental system cost	13-20
Reduced human health externalities	from -29 to -10
Reduced CO_2 externalities	from -128 to -32
Net cost-benefits	from -137 to -29
Incremental subsidy needs	46
Investments (average between today and 2030)	
Incremental investment needs	38
Total investment needs (REmap Options)	77
Total renewable energy investment needs (REmap Options and Reference Case)	86

7.5 Discussion of REmap 2030 Options for US

REmap 2030 growth compared to historical developments

To achieve the estimated renewable energy growth, efforts need to be made on multiple levels to better understand some implications of this growth, renewable energy deployment in the US can be put into perspective with similar trends seen in other countries and projected by other scenarios.

The incremental renewable energy use needed to triple renewable's share of TFEC between 2010 and 2030 in the US, is split equally between the power and end-use sectors. REmap Options in the power sector are dominated by wind, about two-thirds of the total. Biomass use dominates the REmap Options for the end-use sectors.

If all wind REmap Options are implemented by 2030, wind power consumption would account for 22% of the total renewable energy use of the US in REmap 2030, and 20% of the total power generation in 2030.

Total biomass heating (32%), transport fuels (17%) and power (8%) consumption would account for 57% of the total US renewables consumption (Table 5 and Figure 19 above).

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[19] Efficient mitigation assumes that the cost of prevention does not exceed the cost of the damages prevented. The value of the benefits depends on and will vary with the carbon price assumed for the calculation.

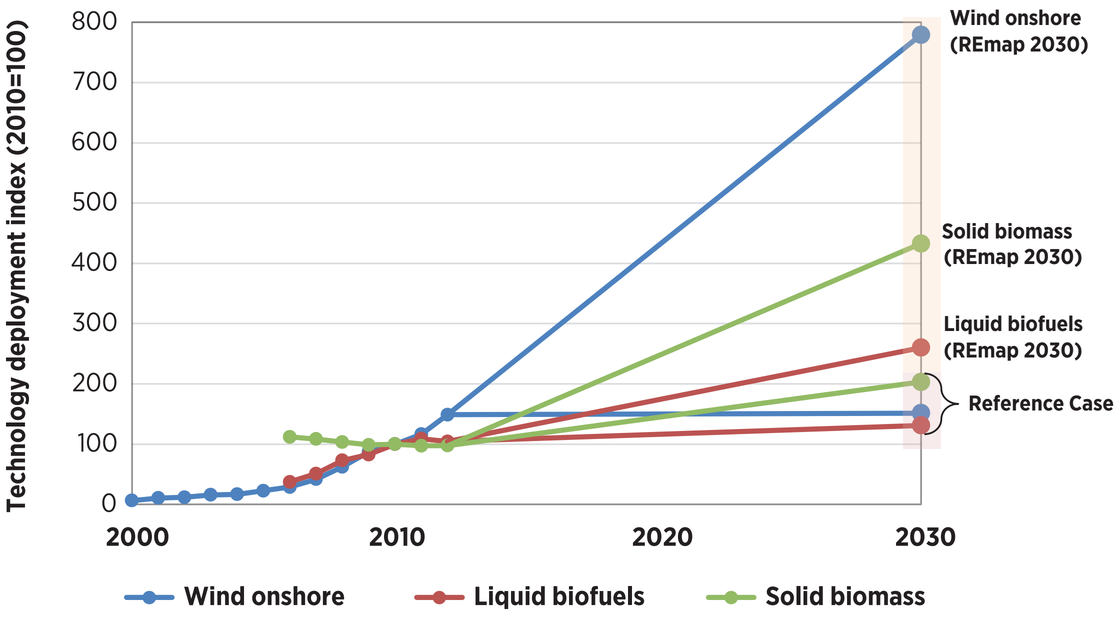
Figure 19 shows the deployment rates for various renewable energy sources in the US under REmap 2030. Compared to 2010 levels, onshore wind generation would grow by more than 10 times, from 96 TWh/year in 2010 to 1,154 TWh/year in 2030. This implies a growth in installed capacity of 14 GW_e per year on average for onshore wind and 2 GW_e per year for offshore wind between 2010 and 2030. Compared to historical capacity growth rates, this is a substantial increase. Annual wind capacity growth increased from 2.5 GW_e/year in 2006 to 10 GW_e/year in 2009. However, in subsequent years annual capacity growth decreased from 10 GW_e/year to 5 GW_e/year in 2010 and 6.6 GW_e/year in 2011. Only in 2012 did capacity additions increase again to 13 GW_e/year. Realising the installed capacity in REmap 2030 would require such annual capacity growth rates to be sustained for the next 16 years. Compared to REmap 2030, the Reference Case underestimates current developments. In 2013, installed wind capacity reached 61 GW_e, which is only 2 GW_e lower than the Reference Case estimate of 63 GW_e for the total of wind onshore and offshore.

The growth in biomass demand according to REmap 2030 is also high. In the entire period between 2010 and 2030, total biomass demand would need to grow by about 4 times. The demand growth for solid and liquid biofuels is different. Liquid biofuels would need to grow by about 2.5 times to about 130 billion litres (34 billion gallons) per year in REmap 2030. This is more than the global production capacity already installed today.

In the period between 2006 and 2011, liquid biofuel production in the US increased by about 18% per year. The required annual growth between 2010 and 2030 is less than this, estimated 5% per year. In view of historical developments, this growth seems feasible. As opposed to today's situation where most demand originates from conventional biofuels, in 2030 around 40% of the total demand would be provided by advanced biofuels (55 billion liters per year). By comparison, cellulosic ethanol production capacity in 2013 in the US was only 46 million litres (12.2 million gallons) per year (Janssen *et al.*, 2013).

The estimated growth in solid biofuels for heating and power generation is higher than in liquid biofuels, by about 4.5 times, from 2.5 EJ in 2010 to about 11 EJ in 2030. This implies an annual growth of more than 8% per year. However, the historical trends between 2006 and 2012 show that the solid biofuels demand is actually decreasing (see Figure 28). This is explained by the decrease in solid biomass use for industrial applications although the demand for power generation and residential heating has slightly increased (UNECE, 2013).

Figure 28: Deployment of wind and bioenergy deployment in Reference Case and REmap 2030, 2000-2030



According to REmap 2030, solid biofuel demand mainly grows for power generation, by about 8 times between 2010 and 2030. About 40% of this growth is attributed to industrial CHPs and 60% is related to the growth in power-alone systems and co-firing. The demand for solid biomass for power generation has been growing rather slowly and has fluctuated between 1.5 and 1.8 EJ per year since 2000. Recently biomass use in industrial applications (incl. CHPs) is decreasing, mainly due to lower activity in biomass consuming sectors such as the pulp and paper sector, but also due to shale gas use in investments for new capacity. As a result, increasing the demand for power generation by 8 times will be a challenge.

The growth rates for biomass demand for residential and industrial heating applications in REmap 2030 are 40% and 220%, respectively. As a result, biomass for heating would nearly triple from 2.1 EJ in 2010 to 5.7 EJ by 2030. Current wood pellets production capacity in the US is around 8.2 million tonnes of which only half is used for production. Planned production capacity is about 15 million tonnes in the next years (UNECE, 2013). If all of the existing and planned capacity was to be fully utilised, it would be sufficient to provide half of the demand in the US residential sector in REmap 2030. The next two sections discuss further the challenges and barriers in wind and bioenergy in the US.

The results of the REmap 2030 show that wind and various bioenergy applications together account for nearly three-quarters of the total renewable energy use in the US. This would mean that the US would rely mainly on these two resources, and would require that all of the different applications of biomass use would be fully and successfully deployed. This creates additional uncertainty given the challenges facing each technology as discussed above. The potential of renewables other than wind and bioenergy, such as solar, geothermal and others, must also be explored further to ensure that a portfolio of renewables is deployed.

Wind power challenges

There are challenges which are specific to each technology to realise the deployment according to REmap 2030. Most of the total wind capacity being developed or under construction (announced capacity of 40 GW_e, and 14 GW_e capacity was under construction by the end of the second quarter of 2014) is located in Midwest (AWEA, 2014; Cleantechnica, 2014c). This implies new grid connections to the rest of the country which will be a challenge to realise in the 2010-2030 timeframe. In total, about a quarter of the power generation capacity in REmap 2030 is based on wind. According to NREL (2012a) grid integration studies showed that up to 30% power generation from wind can be reliably and economically accommodated in the future.

There are two studies looking at grid integration and transmission in the US, covering the west and east parts. The Eastern Wind Integration and Transmission Study (NREL, 2009) looked at the needs to integrate 20%-30% wind in the Eastern Interconnect by 2024. The findings of the study showed that there are no technical barriers to achieving 20% integration, but that a significant transmission line would need to be built; otherwise, a 20%-30% share would not be feasible. The time to build new transmission capacity is longer than new plants, therefore planning is key. A similar study – Western Wind and Solar Integration Study – looked at the needs in the west part of the US for accommodating 30% wind and 5% solar (GE Energy, 2010). The technical analysis provides a number of solutions to reach these levels which include extensive balancing, area cooperation and minimal forecasting errors among others. The analysis also highlighted the importance of sufficient long distance and intra-area transmission within each state or transmission area for renewable energy generation to access load or bulk transmission (GE Energy, 2010). However the results of these studies are presented as least cost options, and other solutions that include less transmission capacity to integrate higher shares of renewable electricity are also possible.

Realising installed capacity of 356 GW_e by 2030 implies a growth of around 16 GW_e per year capacity. About 85% of this growth is related to onshore and the other 15% is for offshore wind. Equipment manufacture capacity would need to be able to meet the needs of the estimated capacity growth. Existing equipment manufacturing industry for onshore wind would need to be expanded to meet the demand and a new industry would need to be established for the manufacture of offshore wind equipment. Although in the past years some bottlenecks have been observed in the manufacture of various equipment along the supply chain, new production capacity has been installed. Today a few companies dominate equipment production market in the US, and growth in production capacity would need to be sustained in the long-term as well. In the particular case of offshore, deployment requires infrastructure built at sea, such as ports and service vessels (NREL, 2012a). The manufacturing, materials, and human resource needs for offshore development could benefit from the extensive offshore oil and gas expertise that exists in many coastal regions of the US. From a technology perspective, NREL (2012a) identified main barriers and uncertainties for high shares of wind deployment where R&D can play a role to increase efficiencies with improved technologies (*e.g.,* advanced power electronic control, direct-drive generators) and ensure that costs (*e.g.,* standardisation and defining refinement for offshore foundations and support structures) are competitive relative to conventional energy sources.

Biomass challenges

As discussed earlier in Section 5.2, the breakdown of bioenergy supply is more or less equal across the three different sources covered by IRENA's analysis: forest products, agricultural residues & waste and energy crops each account for a third of the 2030 estimated total supply potential of 19-23 EJ. According biomass resource estimates made by NREL, the bulk of the forest and primary mill residue supply potential is in Southeast of the country. Additional potential exists also in the Northwest as well. Secondary mill residues are roughly evenly distributed across the country, including Northeast and Southwest. With regard to crop residues, most of the potential is in the Midwest (NREL, 2012b). With regard to energy crops, the growth potential for switchgrass, willow and hybrid poplar is mainly in the Midwest, with some also in Eastern states (Milbrandt, 2005).

The estimated bioenergy demand in 2030 means also the deployment of a large number of biofuel production and power generation and heating plants.

Most of the biomass used for industrial applications will be for CHP plants. Assuming that the capacity factors of these plants will be close to today's levels (about 60%), total installed biomass CHP capacity would reach around 50 GW_e. This means that a substantial share of the biomass power capacity in the US in REmap 2030 would be on-site industrial CHPs. Based on an average power generation capacity of 20 MW_e, this capacity would translate to the need for about 2,500 CHP plants operating by 2030; average investment costs for such a plant are around USD 30 million at today's prices (EPA, 2007). Oregon, Washington, Wisconsin are among the states with large biomass-fired installed CHP capacities today, explained by the availability of feedstock in these regions. Part of the growth in 2030 is expected to happen in these regions with easy access to feedstocks and where already large manufacturing industry exists, but also in locations where much of the chemical (*e.g.,* East Coast and Gulf coast) and food (spread across the region) industries are located in. Since not all these plants will have close proximity to feedstock supply, developing logistics for domestic trade will gain importance. Similarly, to increase the use of solid biomass for heating in the building sector across the country to the levels estimated in REmap 2030 will require the development of biomass logistics. In addition, some local reasons may still need to be resolved. For example, in the Southeastern US, which is the richest in terms of availability of forest bioenergy products, a number of reasons slow down the transition to renewables including concerns about federal control and support for states' rights, the presence of strong coal and nuclear industries, cheap gas prices and very low electricity rates (Wood, 2009).

Conventional biofuel demand is estimated to account for 60% of the total demand with the remainder 40% being from advanced biofuel. A larger share of advanced biofuels production from non-food feedstocks (*e.g.,* residues) which do not compete with land and water resources for food production as is the case today, will help a transition to a sustainable energy system in the transport sector. The use of such feedstocks is especially important in the case of the US where corn products are pervasive in the food industry. Assuming on average 5 PJ per year production capacity per ethanol mill and biodiesel plants, and assuming all production is met domestically, producing 3.1 EJ per year liquid biofuel in the US would require investing in about 600 plants (majority of this would be ethanol mills).

Today most ethanol production is located in states where corn production is concentrated in the Midwest, such as Iowa, Illinois, Nebraska or Minnesota. It can be expected that this will also be the case in the future where most plants will be constructed in the same region given the availability of corn. Advanced biofuel plants using corn residues as a feedstock will also be located in these parts as it is already the case in today's commercial-scale plants under construction (Sheridan, 2013). Given the availability of woody biomass, there are a number of plants being built in the Northwest and Southeast states where such feedstock is available. To ensure cost-competitiveness, high capital cost of advanced biofuel plants need to be reduced (ACORE, 2014b; IRENA, 2013b). While biofuel plants will be close to regions with feedstock availability (mainly Midwest and a number of other regions with wood biomass availability), demand is concentrated in the East and West coasts of the US. The costs related to the delivery will increase the overall supply costs, and not only that, but also the number of blending stations will need to increase with growing demand.

Moreover different transport modes (*e.g.,* rail cars trucks) and other technical issues (*e.g.,* corrosion in pipelines and blending stations and obstacle related to going beyond the E10 blend to E15) related to biofuel logistics will need to be resolved to realise these potentials (Farrey and Chung, 2010). The development of infrastructure to handle higher ethanol blends is very slow and higher ethanol blends have a bad image because consumers believe higher shares could damage vehicles in spite of the fact that there is no significant damage to vehicles produced after 2001 (DeDecker, 2014).

The US is already playing an important role in the international trade of wood pellets and liquid biofuels. If the US continues to be an exporter of bioenergy commodities in the coming years and with increasing demand for biomass in REmap 2030, the limits of biomass supply will be reached. First, additional international demand will create pressure on the limited US biomass resources; second, the deployment of the logistical supply chain supply of the US (e.g., collection of residues, their transport, etc), will become increasingly complex and expensive at a time when US transport infrastructure is already in a parlous state. However, this may, in fact, serve as a brake on international demand.

Several policies are already in place in the US to foster increased sustainable biomass supply and use. These mainly focus on the production of liquid biofuels and its sustainability from a GHG emission perspective; they would need to be expanded to cover the heating and power generation application of biomass. On the demand side, long-term policies setting targets of bioenergy use should also be implemented for heating and power generation applications (see next section). The economic viability of bioenergy is mainly determined by the cost and price of biomass. These are hard to predict, influenced by factors such as logistics, distances in transport, policies, changes in demand, etc. Such factors are relevant to all energy pricing, so that cost and market uncertainty present a certain amount of risk for investors in any energy facility, and in this case could limit the growth of biomass capacity.

Nearly three-quarters of the total renewable energy use in REmap 2030 is related to wind and biomass, but there are challenges in connecting supply and demand centres and the costs associated to these

Variable renewable energy shares and costs

Although a number of studies show that accommodating high variable renewable energy shares in the grid is possible, most show that it will require a substantial expansion of the transmission capacity. However, this is not as simple as building new lines. Based on the analysis of 10 REmap countries with the highest variable renewable energy shares in 2030, IRENA developed a grids roadmap (IRENA, forthcoming a). The main recommendation of this report is that there are different ways to integrate high shares of variable renewables to the grid. Factors such as the existing grid system, interconnection capacity, technology availability and development, policies and institutional framework, technical characteristics of generation such as capacity factors, but also power demand characteristics etc. all are important and vary by country. Hence there is no one-size fits all solution for countries. This diverse set of options is also highlighted in the NREL's Renewable Electricity Futures Study. The study provides additional scenarios showing how higher shares of renewable electricity can be achieved if there is limited expansion of transmission capacity or constrained power system flexibly.

For example, Denmark is estimated to have a variable renewable energy share of more than 80% by 2030, mostly coming from one type of renewable energy: wind. Relying on its well-structured interconnector capacity with the neighboring countries through the Nordic Power Exchange, Denmark can achieve such high shares. The country is also using tools for demand forecasting as well as relying on biomass for dispatchable generation. Germany, another example with high variable energy shares of nearly 75% in 2030, is a much larger country in comparison to Denmark. However, it has a strong institutional framework and planning efforts that include an expansion of transmission capacity and policies aimed at diversifying its renewable energy mix that will help the country to reach such high shares. There are also energy storage technologies which are being developed for various applications, including household PV systems with storage to promote self-consumption, smoothing renewable energy supply from wind and solar PV as well as regulation in grids with high variable energy shares (IRENA, forthcoming b). Smart grids are another option that integrate information and communication technologies to the electricity generation and consumption chain to improve reliability, costs and efficiency (IRENA, 2013c).

In the US a mix of different options will be needed to help realise the variable energy shares in this study, but more importantly there needs to be research and discussion about what the shares in this study – if achieved by 2030 – mean for the decades after. The very high levels of variable renewable energy seen in Denmark and Germany will only occur in the US after 2030, when shares will approach the levels analyzed by the NREL Renewable Electricity Futures Study in 2050. New policies will need to address the medium term (up to 2030) needs in each region to achieve the right technology mix. The main barrier nationwide for the US at the moment is the technical feasibility of expanding the transmission capacity within some regions within the next few years.

The REmap analysis is a macro analysis of the options for the US and needs to be supported by detailed, system-wide modeling of specific expansion plans to identify if certain regions in the US with high levels of variable renewable power will have sufficient spinning reserve capabilities to meet ramping that is sometimes required with the variability of wind and solar. Better forecasting techniques for wind power as well as advanced inverters for solar PV that reduces the demand for energy storage are approaches to maximize power output. At a macro-level, these will not be an issue until variable renewables meet very high levels of penetration, as the US has significant thermal power capacity that is available in cases where capacity from solar PV and wind are too low to meet demand. The key issue is whether the is enough capacity in the right locations through time to meet the ramping needs and how other approaches such as demand side management, interconnection and storage fit into a system that is able to integrate increasingly high shares of variable renewable energy.

Moreover, the investment required for transmission for renewable power also tends to be higher than that for conventional central-station power because of the distances from population centers, because the relatively smaller size of renewable generation facilities that raises the *per* MW cost of transmission capacity, and because the variable nature of some renewable energy sources results in higher grid stability and balancing costs.

Such power system operation and cost effects were outside the scope of this analysis as it did not looked into grid integration or system related costs resulting from higher levels of renewable energy deployment. NREL's Renewable Electricity Futures Study (NREL, 2012a) provides a comprehensive analysis of many of the technical issues and costs relating to the operability and integration of high levels of renewable energy. The power sector renewable energy options for REmap were based on the NREL study. The NREL study explored "grid integration issues using models with unprecedented geographic and time resolution" and finds that "renewable electricity generation from technologies that are commercially available today, in combination with more flexible electric system, is more than adequate to supply 80% of the total US electricity generation in 2050" (NREL, 2012a).

The study looked into requirements for grid storage and flexible demand-side technologies, as well as transmission infrastructure. It provides a variety of cost metrics that include investment needs for new generation, storage, interruptible load, transmission, O&M, and fuel costs. However the result of their assessment shows the associated costs of their various scenarios only for the year 2050.

In Table 10 the associated costs of several of the renewable energy scenarios are shown based on their analysis. A renewable energy share of 30% by 2050 (not all variable renewables), would have no effect on the average retail electricity price. However, higher shares of up to 60% or 90%, can result in increase on average of 20% and 35%, respectively (NREL, 2012a). While a one-to-one comparison to REmap 2030 results is not possible due to the 2030 timeframe of REmap, the estimates provide an indication of the potential changes

Table 10: Direct power sector costs of renewable energy scenarios for 2050

NREL Futures Scenario, renewable energy share (%)	Average Retail Electricity Price in 2050 (USD/MWh)	Change relative to power sector price baseline (%)
Baseline (roughly same fossil contribution as today)	111	–
30	109-113	-1 to +2
60	125-137	+12-24
90	140-165	+26-49

Source: NREL (2012a)

in electricity prices on a pathway to such high levels envisioned in NREL for 2050.

IEA also have estimates of the integration of renewables which could add an incremental USD 5-25 per MWh: USD 3-5 per MWh in back-up capacity costs; USD 1-7 per MWh into maintain grid stability; and USD 2-13 per MWh in extra transmission and distribution to demand centers (IEA, 2014). As the data indicates, ranges associated with the additional costs of integration are wide. Similar to the way how much variable energy shares can be integrated into the grid depends on the country, costs of integration are also country specific. Although it may provide an indication, experience in the costs in one country may not be applicable to another. This is, however, one of the most important areas which requires further research by accounting for the specific case of the US.

A 2012 study looking into the marginal economic value of variable renewable energy found that as penetration levels of these technologies increase, the marginal value of the power they generate declines (Mills and Wiser, 2012). A recent report by the Lawrence Berkeley National Laboratory (LBNL, 2014) explored strategies for mitigating this reduction in economic value of higher variable renewable power shares. In REmap 2030, the share of wind power and solar PV in total power system capacity reaches 25% and 10%, respectively. According to the LBNL (2014), implementing a range of measures will increase the cost of variable power generation as shares increase compared to a scenario where no measures were taken. Scenarios with 20% and 30% wind penetration were presented, and when interpolating results for the 25% share of wind found in REmap, the best choice of measures include: demand-response programs using real-time pricing (increase in value of wind by USD 4.3 per MWh), geographic diversity of wind turbine siting (USD 3.8 per MWh), quick start natural gas peakers (USD 0.3 per MWh), and a having a 10% share of solar PV in system capacity (USD 0.1 per MWh). The study shows that when reaching higher shares of variable renewable wind power, measures addressing demand-side energy management, geographic siting, fast start dispatchable power generation, and deployment of solar PV all increase the value of wind power compared to a scenario where these measures were not taken.

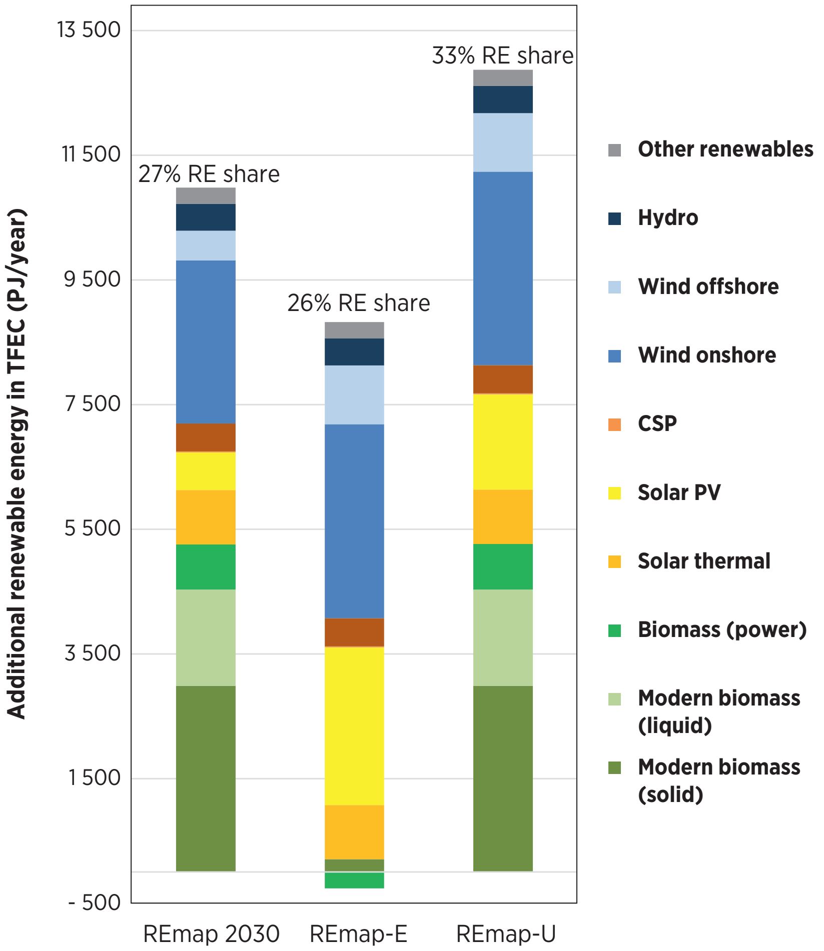
Furthermore, although the average share of variable renewables in generation is estimated as 27% in 2030, given the size of the US, a better understanding of developments at state and regional levels will be required. Compared to this country-average, in some states higher variable renewable energy shares will be achieved (such as wind in Iowa and solar PV in California and Arizona). In addition, further insight needs to be gained into how the variable renewable energy shares can be accommodated at the state and regional level.

The case of electrification

The REmap analysis showed that biomass resources in the US are large and could be sufficient to meet the potential in REmap 2030. However, affordable and sustainable sourcing of biomass remains an important question. The concurrent deployment of alternative and complementary renewable energy resources can help to reduce the potential dependence on biomass.

For heating, alternatives are limited, especially in the case for high temperature process heat generation in the manufacturing sector which can only be generated from biomass (or fossil). In the buildings and district heat sector, solar thermal, heat pumps and geothermal are alternatives. Although the REmap shows they offer large

Figure 29: Renewable energy technology options in the cases of REmap 2030, REmap-E and REmap-U, 2030



Note: REmap-E results in a reduction of biomass consumption shown with the negative value in the graph

potential, on-site land availability, access of plants/buildings to resources as well as costs could be constraints.

In the power sector, there are plenty of alternatives. Solar PV, onshore/offshore wind, CSP, hydro, geothermal, ocean/tide/wave technologies all have further potential beyond what is estimated in REmap 2030. In the transport sector, liquid biofuels play by far the most important role to raise the sector's renewable energy share. Next to the use of biofuels, the contribution of electric vehicles and modal shift are, however, rather limited. However, both electrification options are commercially viable and their deployment could be accelerated instead of or in tandem with, liquid biofuel growth.

Electrification also offers the potential to reduce fuel use for heating. To further explore and clarify the renewable electricity potential, an additional set of REmap options expressly for power generation was created, REmap-E, which considers a more radical electrification scheme than REmap 2030. It essentially replaces all biomass with electricity from renewables. In REmap-E, it is assumed the deployment of three technology strategies to reduce biomass dependency and increase the share of electricity in end-use sector. In the building sector, heat pumps deliver the required heat in the building and industry sectors instead of biomass (for low temperature process heat). In the transport sector, modal shifts (public trams, electric buses and trains) can replace liquid biofuel. Increased electricity demand of these end-use sectors would be supplied by additional solar PV and wind on/offshore capacity. Additional solar PV and wind generation could also replace power that would otherwise have been generated by biomass.

In 2030, the result of electrification in the manufacturing industry results in an increase in electricity demand resulting from a switch from biomass fuels to heat-pumps around 280 TWh/year. The resulting shift of industry to areas where ample, cheap renewable electricity is available results in an increased electricity demand of 160 TWh/year.

Figure 19 compares the renewable energy share in the energy mix of 2030 under three possible futures for 2030: REmap 2030 and REmap-E (both specific to the US) and REmap-U, which shows how a 30% renewable energy share could be achieved on a global basis. Note that the share of renewables in TFEC would be slightly lower with electrification technologies replacing biomass, even if that additional demand is met by renewable power generation. Nonetheless, under this scenario, it would be possible to achieve a renewable energy share in TFEC of 26%, amounting to still nearly a tripling of the total renewable energy share between 2010 and 2030. The reason why the renewable energy share in REmap-E is slightly lower than REmap 2030 is because the amount of biomass used in REmap 2030 is considerable and the amount of energy it would deliver cannot fully be met with electrification technologies alone.

Figure 27 shows the development of REmap Options in REmap-E compared to REmap 2030. Biomass demand in the US is assumed to increase to 5.3 EJ by 2030 instead of 13 EJ in REmap 2030. This translates to a modest increase of approximately 1.1 EJ in biomass demand by 2030 compared to today's levels. This growth assumes that the biomass demand in the industry and transport sectors remain at the Reference Case level. Compared to REmap 2030, this is more than halving the demand for total biomass in both of these sectors. Compared to the Reference Case, biomass use for power generation is also halved. In the building sector, demand consumption increases by only 4% between 2010 and Reference Case.

Figure 27 also shows the breakdown of renewable energy use in REmap Options. In REmap-E there are only minor additions of biomass use from the building sector. In comparison, due to electrification in end-use sectors the additions to solar PV (yellow bars), wind onshore and offshore are higher compared to REmap 2030. The total capacity of solar PV and wind reaches 460-520 GW_e and 420-440 GW_e in REmap-E compared to 135 GW_e and 356 GW_e in REmap 2030, respectively. This also raises the share of variable renewables from 5% to over 30% of generation, implying that even more efforts will be required in ensuring grid stability compared to the REmap 2030 case.

Another important finding is that REmap-E results in a lower TFEC in 2030 of 59 EJ compared to 65 EJ in REmap 2030. This is a saving of nearly 10% with the main reason being the higher energy efficiency of electrification technologies over combustion energy systems when viewed in final energy terms. As a result, even with a smaller increase in EJ from the REmap Options in REmap-E, a similar share of renewables can be achieved as in REmap 2030.

Another strategy for doubling the global renewable energy share is represented by the case of REmap-U (also shown in Figure 27). In this case, all countries are assumed to reach at least 30% renewable energy share by 2030 regardless of where they stand today, using a generic mix of different renewable energy technologies. While some countries would need to substantially increase their renewable energy shares from today's very low levels to 30%, others would meet, or even surpass, this level according to their Reference Case developments.

A number of technology options and strategies are required to ensure that all countries reach at least 30% by 2030. According to REmap-U, the first strategy in all countries is to reduce energy demand by implementing energy efficiency measures. The reduction potential would differ for each country, varying with the growth of energy consumption and the current level and distribution of energy intensity. For the US an energy efficiency improvement of 2% was assumed. The second strategy involves using increased electrification technologies for countries that do not achieve a 30% renewable energy share after the REmap Options and energy efficiency improvements are considered. This includes the US. The electrification technologies chosen for US are those used in REmap-E, with the exception of industry relocation, which is not considered, and with an increase in biomass imports of around 1.3 EJ/year. As shown in Figure 27, REmap-U takes the US renewables share to 32%, using more solar PV and wind REmap Options for electrification than in REmap 2030.

Substitution costs of REmap-E and REmap-U are estimated to be somewhat higher than for REmap

2030. Among the three cases, REmap-E is the most expensive, resulting in an average cost of substitution increasing from USD -0.9 per GJ in REmap 2030, to between USD 1.1 and 3.3 per GJ depending on how the increase in electrification is met by a mix of renewable power technologies and the potential needs for supporting infrastructure. In this case, additional renewable power generation is met by a mix of solar PV and wind, which represent an increase of 300% and 20% over REmap 2030 levels, respectively. The cost increase relates largely to the increase costs assumed with installation of the electrification technologies (electric vehicles, electric public transport, and heat-pumps). For the case of REmap-U, the cost of substitution is higher than REmap 2030, but lower than REmap-E. The range for the cost of substitution is estimated as USD 0.7-2.7 per GJ. The cost impact is lower explained by the fact that only an increase of about 50% of the REmap-E total electrification is realised in REmap-U. Additionally the assumed energy efficiency improvements yield cost savings since less renewable energy capacity is required.

Comparisons to other scenarios

There are many studies which look at the short- and long-term developments in the US energy use as well as the potentials for renewable and energy efficiency technologies. Studies are conducted by national research institutes (*e.g.,* such as the various Department of Energy national laboratories) as well as organisations active in the global debate on energy issues (*e.g.,* Greenpeace, IEA). The aim of this section is not to provide a detailed comparison of REmap 2030 findings to each one of these studies; the aim is rather to provide a comparison to recent ones.

The basis for the accelerated deployment of renewable energy technology for power production identified in the REmap Options is IRENA's interpretation of the NREL's Renewable Electricity Futures Study. The NREL Study provides several cases for 2050, for the REmap Options the "80% RE-ETI" (evolutionary technology improvement) scenario was used, reflecting a "more-complete achievement of possible future technical advancements" (NREL, 2012a). Generally the renewable power technologies mix contained in this report is consistent with the NREL projections, although some variability could exist due to variations in the reference case and assumed deployment rate.

In May 2014, Greenpeace published the US edition of the Energy Revolution (Greenpeace, 2014). According to its Energy Revolution scenario (most ambitious climate policy scenario), Greenpeace projects a TFEC of 46 EJ by 2030, 19% of the 2011 base year of the study. The estimated TFEC in REmap 2030 is 40% higher than Greenpeace projections. The main difference stems from the TFEC of the transport sector where Greenpeace projects a saving of 32% compared to 2011 levels whereas REmap 2030 estimates only 5% decrease. Installed renewables capacity according to Greenpeace is 1366 GW_e (mainly 568 GW_e wind and 339 GW_e solar PV) compared to 488 GW_e of conventional generation capacity. In REmap 2030 a much lower renewables capacity is estimated of 716 GW_e and a higher conventional generation capacity of 681 GW_e. The renewable power generation share according to Greenpeace can reach 71% in 2030 compared to 48% in REmap 2030.

The renewable energy share in end-use sectors also increases substantially according to the Greenpeace projections in 2030: 57% in buildings, 51% in industry, and 18% in transport. This is partly explained by the higher share of electricity use in TFEC (30% compared to 25% in REmap 2030) and a share of renewable electricity generation as high as 73%.

Another interesting outcome of the comparison is that Greenpeace projections rely on only a limited amount of primary biomass demand of 5.5 EJ compared to more than 16 EJ primary biomass demand in REmap 2030. This shows that Greenpeace projections follow a combined strategy of energy efficiency and electrification technologies to raise the US renewables share to as high as 41% compared to REmap 2030 estimates of 27% based on somewhat stable growth in TFEC in the period 2010-2030 and mainly bioenergy and wind being the renewable energy resources.

IEA's World Energy Outlook 2013 provides various scenarios to 2030 for the US (IEA, 2013b). The most ambitious climate policy scenario, the 450ppm scenario, projects a renewable energy share of 25% in the US total energy mix in 2030. This is comparable to REmap 2030 estimates of 27%. However, there are differences in the growth in demand, capacity and contribution of renewable energy technologies to this total.

Compared to 2010 levels, according to the IEA, TFEC of the US decreases by 8% to 52 EJ as opposed to an approximate 15% increase of 65 EJ according to REmap 2030. Hence a higher level of energy efficiency improvements is assumed for by the IEA. Given that a similar level of renewable energy share is achieved in 2030 in both the 450ppm scenario and REmap 2030, this implies a lower absolute renewable energy use in the 450ppm scenario.

According to the IEA, power generation in the US increases by 9% compared to 2010 levels to a total of 4,710 TWh/year in 2030. This is about 500 TWh/year lower than the REmap 2030 estimates of 5,220 TWh/year. One of the drives is the increased electrification in the end-use sector identified in the REmap analysis. The renewable share in power generation is also lower according to the IEA, estimated at 32% with half of that being solar PV and wind. The breakdown of renewable power generation shows similarities for all technologies with the exception of CSP. About 112 TWh/year power generation from solar CSP is assumed according to the IEA from a total installed capacity of 29 GW_e compared to only 8 TWh/year generation in REmap. In terms of absolute capacity growth, REmap estimates about 50% higher capacity for wind and solar PV compared to the IEA and a factor two higher for biomass (incl. industrial CHP) and geothermal.

Total primary energy demand according to both the 450ppm scenario and REmap 2030 are similar, estimated at 14 EJ and 16 EJ, respectively.

8 BARRIERS AND OPPORTUNITIES FOR RENEWABLE ENERGY TRANSITION

Key points

- Most coal and nuclear plants are reaching the end of their life in the coming 15 years and this opens up special opportunities to introduce renewables despite anticipated constant electricity demand,
- Low cost shale gas presents a challenge, although gas prices have recovered from recent lows and hover now around USD 4-5 per GJ, at which level for example wind can compete,
- Specific major impediments include the need to accommodate intermittence and lack of suitable interconnection and transmission capacity and the long planning procedures for interstate power lines.

8.1 Energy system characteristics

As shown in Figure 9, energy demand in the US has recently been relatively flat, with fossil and nuclear power generation accounting for 87% of power generation in 2013. As a consequence uptake of renewables under any circumstance would tend to imply largely the replacement of existing fossil and nuclear based capital stock, using renewables to drastically reduce CO_2 emissions, replacement of fossil fuels by renewable energy is a major goal. In either case, such replacement is primarily and realistically limited by the relative generating costs and efficiencies, by reliability constraints and by the age profile of the existing capital stock if massive stranded costs are to be avoided in the transition process.

This question of capital inertia is significant. Fossil and nuclear power plants accounted for 87% of power generation in 2013; both have a long plant life expectancy. Coal plant age averages around 36 years and nuclear around 30 years (US EIA, 2013b), with plant life extensions up to 60 years not uncommon. Natural gas plants have an average plant age profile of around 18 years (see Table 11), reflecting the concentrated construction of new plants in the last decade.

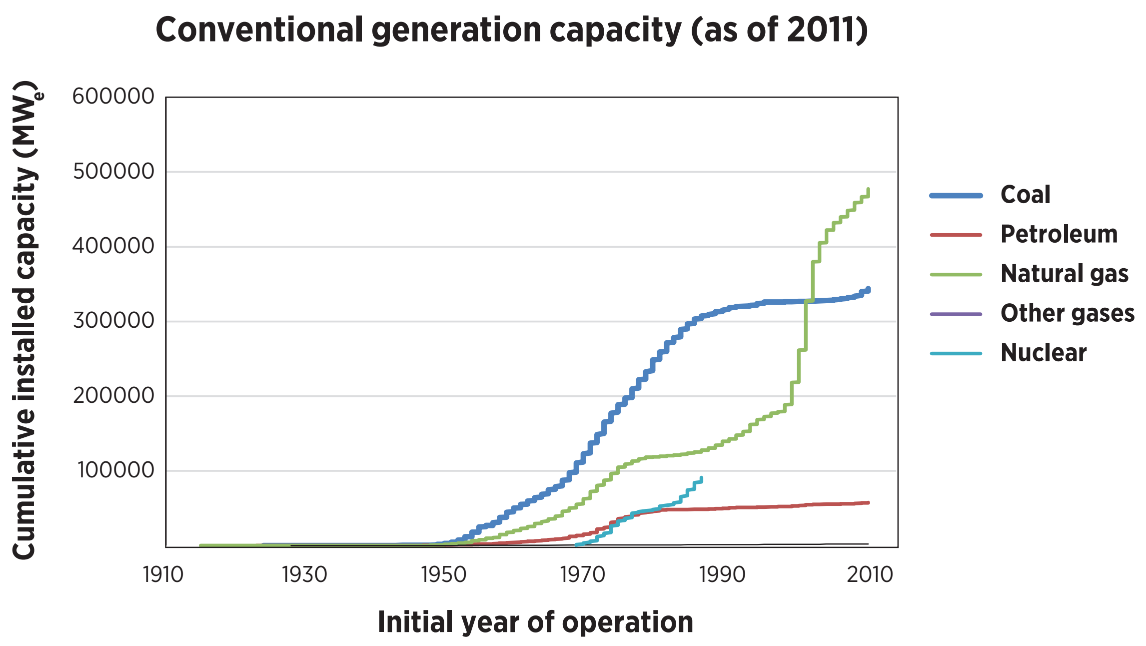
Table 11: Total installed capacity and weighted average age based of the generation capacity

	Installed capacity (GW_e)	Average age (years)
Conventional fuels		
Coal	344	36
Petroleum	58	35
Natural gas	477	18
Other gases	2	33
Nuclear	107	30
Renewables		
Conventional hydro	78	51
Wind	46	4
Solar thermal and PV	2	7
Wood and its products	8	30
Geothermal	3	24
Other biomass	5	17

Source: IRENA estimates based on US EIA (2013b).

Note: Only utility size capacity is included, excluding plants smaller than 1 MWe.

Figure 30: Cumulative conventional power plant capacity and their initial year of operation



Source: US EIA (2013a)

Figure 30 shows the cumulative conventional power plant capacities as of 2011 as a function of the initial year the plant operation. Natural gas plants have seen the most increase (light green line). By comparison, little coal capacity has been added since 1980s (dark blue line). Most coal plants in operation were installed before 1980 and can be expected to be retired by 2030, assuming a lifetime of 40 to 50 years. Coal continues to be challenged by cheap gas and tougher environmental regulations.

As a result of the EPA Clean Power Plan, generation owners have recently announced 47 GW_e of coal-fired capacity retirements for 2015 and beyond in the Eastern Interconnection alone, a significant increase just in the last two years. Renewable power technologies such as wind, utility scale solar PV, biomass and geothermal may provide options for replacing part of this retired capacity.

Given the aging power system of the US, investments are required for new high-voltage lines and improve the existing ones. However, there are barriers to expanding the transmission structure and grid optimization. Technical and economic barriers play a lesser role. The main barrier in the US is the existing institutional framework which does not sufficiently provide for the required planning and building of the transmission grids and where no authority exists to do enforceable energy system planning (Jimison and White, 2013). Permitting and licensing requirements and endless regulatory approvals to chase, stemming in large part because lines usually cross property owned by hundreds of different private landowners, as well as various government agencies.

Most coal and nuclear plant are reaching the end of their life in the coming 15 years and this opens up special opportunities to introduce renewables despite the constant electricity demand

Furthermore, developing technology to harvest the plentiful renewable resources, operating procedures to integrate them on the grid, and regulatory structures to ensure that the grid is reliable and that value and costs are shared appropriately among stakeholders are main implementation challenges. The remote location of renewable energy resources and their high variability requires a new level of wide-area coordination across traditional physical, ownership, and regulatory boundaries. It will therefore be necessary to develop technical, operational and regulatory structures that enable these integration challenges (APS, 2011). It should be noted that while integration of intermittent power to the grid is a concern rather unique to renewable energy, grid management and regulatory issues are not.

A number of specific grid connection concerns are worth noting. First is the connection to the grid of good wind resource areas in the Midwest to centres of demand on the East and West. High voltage DC lines are the preferred mode of connection over such long distances. Extra high-voltage lines of 765 kV can carry the three times the amount of power single 500 kV lines would carry. In addition, losses in the power transmission also decrease with high voltages. The costs of such high voltage lines (USD 2.6 million per mile) are also lower by up to 70% compared to 345 kV (USD 9 million per mile) and to 60% compared to 500 kV lines (USD 6.9 million per mile) (ETA, n.d.).

NREL sees a need for about 120 thousand "Gigawatt-miles" of new transmission, an investment of USD 6.5 billion per year between now and 2050 to reach 80 percent renewables. Most of this would be built in the sparsely-populated wind belt. This would add about 60-80% to the existing grid capacity. Some of this capacity would need to be built under any circumstances to accommodate growing demand, regardless of how rapidly renewable power replaces conventional power. But the geographic configuration of the grid will definitely be affected by the deployment of renewable resources.

The Midwest has already successful in integrating 12 GW_e of wind (10% of the Midwest Independent System Operator's total generation capacity) with few difficulties. Geographic diversity (varying wind speeds in different parts of the region throughout the day), better forecasting, transmission expansion and upgrades and learning from the experiences of grid operators across the US and from other countries helped to make this transition easier for the Midwest (Jimison and White, 2013).

Market fragmentation and bureaucratic procedures which apply to both conventional and renewable energy technologies, result in relatively high prices of certain renewable energy options compared to other options. Soft costs (or non-hardware costs) which are related to permitting, inspection, interconnection, overhead, installation labor, customer acquisition, and financing, could be substantial. They could represent about half of the total installed solar PV prices (Ardani *et al.*, 2013).

Grid connection is considered as a major barrier to renewable energy capacity investments. There are restrictions on interconnecting non-utility generators to the grid system. Many if not most renewable energy facilities are independent power producers (IPPs), and so are subject to such non-utility and small business requirements. These can add costs that reduce the economic viability of renewable energy projects (Walsh, 2013).

The lack of sufficient interconnection capacity and the long planning procedures for interstate power lines act tend to hinder grid expansion, potentially limiting integration of both new conventional and renewable generation into the grid. Particularly difficult for distributed renewable power are low capacity limits in several states resulting in the applicability of some interconnection procedures to a small market only. Additional factors that can increase the costs of small distributed generation systems include liability insurance (Fink, Porter and Rogers, 2010), and lengthy and difficult interconnection approval processes (Alderferer, Starrs and Eldrigde, 2000). In the specific case of offshore wind, technical barriers including installation and grid interconnection and the lengthy permitting processes were found to be the main barriers (US DoE, 2012). A study focusing on the policies in Michigan found that inconsistent permitting processes by jurisdiction and varying interpretations of the tax code for solar systems were the main barriers to limit commercial and residential market expansion of solar PV (Miller *et al.*, 2012).

The building sector in the US provides opportunities for increased renewable energy technology deployment, both in old building stock and new builds. However new buildings are expected to account for only a quarter of total floor space by 2030. Therefore retrofits of old buildings, and the codes that determine how they are made, will play an important role in determining the energy profile of the sector. When a building is retrofitted, new space heating, water heating, and cooling systems are often also installed. This provides an opportunity for the installation of renewable energy technologies such as geothermal or aerothermal heat pumps (for space heating and cooling), biomass pellet heaters, and solar thermal systems (for domestic hot water). The US has the largest cooling demand in the world: half of the energy consumed for cooling worldwide is consumed in the US. This leaves significant opportunity to increase the techno-economic efficiency of these cooling systems through the use of heat-pumps, as well as solar cooling technologies.

The age of the industry sector capital stock in the US is rather old. Most plants are 25 years or older (IRENA, 2014b). Investments to new industrial capacity were limited until a few years ago, when growing availability of natural gas, led to new capacity investments in some sectors (*e.g.,* chemical and petrochemical plants), implying the strong relationship among industry investments, energy security and energy prices. This relationship creates both barriers and opportunity for renewable energy in the manufacturing industry. Solar thermal, geothermal and biomass are all alternatives for heating, but access of plants to resources and security of supply, in particular in large energy consuming plants, increase the risks. In comparison, solar thermal is already being deployed in the US manufacturing plants, showing that it is a cost-effective option in some regions and applications. Some waste and residue feedstocks are also comparable with coal prices on a GJ basis.

In the transport sector, options are limited to liquid biofuels and electric transport modes. There are significant technical and economic barriers to the deployment of advanced biofuel technologies. The success of biofuels first depends on their compatibility with the existing transportation system which requires fuel testing and certification processes. The cost of all types of bioenergy commodities depends on feedstock prices, which are uncertain. Furthermore, new technologies need to be developed which can convert cellulosic feedstocks efficiently and at low cost to final products.

Box 5: Innovation in Massachusetts

Massachusetts has become an early leader in clean energy research, innovation and deployment, thanks in part to its scientific expertise and highly qualified workforce. In the absence of a federal approach to energy issues, Massachusetts is one of the US states that have taken control of its own destiny in developing clean energy. It has committed to reducing GHG emissions by 25% in 2020 and by 80% in 2050, both compared to the 1990 level. The Commonwealth was the first in the country to combine energy and environmental agencies to increase the ease of deploying clean energy and leads by example in reducing energy use and greenhouse gas emission in state agencies. It made energy efficiency its first fuel and has led the nation for three years, as ranked by the American Council for an Energy Efficient Economy. Massachusetts was the first state to legislate a RPS in 1998, and has successfully kept pace to meet its minimum standard for new renewable energy generation which grows to 15% in 2020. Finally, the state has prioritized clean energy growth through innovation and entrepreneurship.

As a result of these initiatives, more than 5,500 clean energy firms are doing business and more than 80,000 clean energy workers are employed in the state as of 2013. The state has experienced nearly 30% growth in employment related to clean energy jobs in the past three years. Clean energy also substantially contributed to the economic growth of 2.4% experienced in the first quarter of 2014.

Since the launch of the state's solar PV carve-out of the RPS program in 2010, the installed capacity has risen from a few MW to nearly 600 MW in the middle of 2014. A second phase program was recently launched to maintain solar growth to 1 600 MW by 2020. Massachusetts also focuses increasingly on offshore wind development, with the establishment of the nation's largest offshore wind blade testing facility in Boston, the build-out of an offshore wind staging terminal in New Bedford and the anticipated first US offshore wind project once the Cape Wind project gets built.

The state is also one of the first in the US to adopt mandates for renewable heating and cooling. In 2014 the state passed a bill allowing system owners utilizing renewable heating and cooling technologies such as heat-pumps, wood pellet burners or biomethane burners to earn alternative energy credits that are needed by utilities to meet the state's RPS obligations.

8.2 Fossil fuel pricing

The US has some of the lowest fossil fuel prices in the world. Unlike other developed markets such as the EU, the US has no carbon price or system of capping and trading emissions (though California has recently enacted an emissions cap-and-trade scheme). These two factors have led to inexpensive fossil based power and heat generation utilizing natural gas and coal – both of which are below world benchmark prices due to ample domestic supply. However petroleum products are more closely aligned with world prices. Unlike other developed economies, the federal gasoline tax in the US remains unchanged since the 1990s and at USD 18 cents per gallon (USD 4.8 cents per litre) and does not align with the substantial increase in the oil prices since then. When local and state taxes are included the average fuel tax amounts to 49 US cents per gallon.

Recent years have shown power generation switching from coal to gas and this trend will depend on relative coal and gas prices and the viability of renewables to meet wholesale supply needs. In early 2013 coal consumption in power generation increased 14% compared with the same period in the previous year, as natural gas prices at Henry Hub increased by around 40% from USD 2.58 per GJ (USD 2.45 per MBtu) in 2012 to USD 3.68 per GJ (USD 3.49 per MBtu) in the same period of 2013. Absent environmental or other regulations restricting CO_2 emissions for existing power plants, coal plants could again become economic relative to gas with natural gas prices in the range USD 4.7-5.8 per GJ (USD 4.5-5.5 MBtu) or higher. However the recently announced EPA standards for existing coal power plants, if implemented, would significantly restrict coal power plants on CO_2 grounds unless CCS technology is able to be deployed.

As mentioned earlier in Section 3.2, the slight increase in energy price projections will result in continued price pressure for renewables trying to compete in the electricity wholesale market with natural gas based generation.

Gas prices have recovered from recent lows and hover now around USD 4-5 per GJ, at which level wind can increasing compete on the wholesale power markets without subsidy

9 SUGGESTIONS FOR ACCELERATED RENEWABLE ENERGY UPTAKE

This section starts by discussing the key characteristics of US policy making and draws conclusions about what this implies for successful policy proposals (Section 9.1). It continues with the recommendations for new policies to raise the renewable energy share to the level of the potentials estimated in this report (Section 9.2). It ends with a discussion on the relevance of REmap findings to the mitigation of climate change (Section 9.3).

9.1 Key characteristics of the US policy framework

IRENA analysis suggests a significant potential for renewable energy, up to 27% of final energy by 2030. This is lower than the 36% objective for the world as a whole, but not surprising for a country that has huge and varied resources of fossil fuels (Elliott, 2013).

The feasibility, efficiency and effectiveness of policies depend on the characteristics of the national energy policy governance system. What works in Europe or China cannot be directly transferred to the US, and vice versa. But general recommendations are possible, for example, that policy support must be consistent, predictable and long-term if renewable energy is going to make a significant contribution (Randall and Porter, 2006).

Governments in general find themselves continually needing to balance any number of competing objectives, interests and demands on the public fisc. The political process by which this balance is achieved is less than optimal from any perspective. The US is no exception. Private and public interests are seldom consonant, and changing the status quo requires political effort. Under such circumstances, effecting dramatic changes in the US energy sector is a daunting task, though not necessarily impossible. A concerted focus will be needed at all levels of government to overcome regulatory and economic inertia and bring about an accelerated switch to renewable energy as envisioned by REmap 2030. The president approves legislation and is involved in setting the policy agenda, but policy changes often require effective legislation, which falls to the Congress. The actual job of implementing a policy falls to the different executive departments and to the states. State environmental, consumer protection and regulatory agencies play a crucial role. As regards renewable energy, several Federal agencies play a key role. Below is a brief list of the agencies with an important role to play in accelerating the deployment of renewable energy technologies, and a summary of their mission.

Knowledge – The EIA collects, analyses, and disseminates independent and impartial energy information to promote sound policymaking, efficient markets, and public understanding of energy and its interaction with the economy and the environment. Its data, analyses, and forecasts are independent of approval by any other officer or employee of the US Government, including DoE. It has a budget of nearly USD 100 million per year.

RD&D, innovation and transition management – the mission of the DoE is to "ensure America's security and prosperity by addressing its energy, environmental, and nuclear challenges through transformative science and technology solutions".

The FERC is responsible for competitive markets, energy infrastructure and oversight. This includes interstate electricity transmission and hydroelectric projects. On a local and state level, usually state public utility commissions are responsible for setting retail electricity rates, approving construction of in-state power plants, regulating mergers and acquisitions of in-state energy companies and ensuring the reliability of the electricity distribution network.

The EPA uses its standard promulgation powers to force policy changes in sectors of the economy for environmental protection. As discussed in Section 8.1 a recent example is the EPA's June 2014 proposal (EPA, 2013b), which if implemented, will regulate the power sector's carbon intensity, and requires states to meet CO_2 intensity levels for their power generation sector.

Within these various agencies support for renewable energy has been mixed, and does not yet reflect a sense of urgency. Nonetheless, there are perhaps a surprising number of federal policies supporting renewable energy deployment to date. These include variously renewable energy targets for utilities for generation mix, preferential dispatch for renewable generation, feed-in tariffs, tax incentives, preferential pricing, R&D subsidies, blending requirements for biofuels, funding and guidelines for industrial co-gen, and a North American Smart Grid Interoperability Panel to coordinate and accelerate standards harmonization.

Moreover, climate is now recognized as a serious issue and attention to energy efficiency and renewable as solution to the problem has grown, with a presidency that is trying to set an ambitious agenda. The policy recommendations reflect the possibilities within the existing framework.

In this regard, it is particularly important when considering next steps to recall the major shift that occurred in US regulatory policy in the 1990s. In that decade, the rapid technological changes in the US gas and electricity industries resulted in the restructuring of those industries and a dramatic change in their regulation. With the industries more competitive at every level, regulatory policy changed from traditional "command and control" to one where regulators set up economic incentives within a framework of specific goals, depending on market responses to effect the desired changes over time. This reliance on economic instruments to bring about policy changes could be applied usefully and creatively in structuring incentives for a massive switch to renewable energy. Innovative financing schemes can be an important part of such incentives. In fact a number of investment banking houses have already devised innovative financing schemes for renewable energy projects designed to permit investors to profit from existing financial and tax advantages attached to renewable energy, while minimizing their investment risks.

The risks of investing in renewable are greatly reduced by the fact that virtually all of the ancillary and integration costs needed to make a project viable are not borne by project developer; they are generally borne by consumers in the form increased energy costs or by consumers as taxpayers. Nonetheless, creative financing schemes are being developed to further reduce project risks. One example limits the capital outlay for a solar project to the ownership of solar panels, installed on rooftop space leased from building owners. The building owner gets cheaper power and rent; the panel owner earns his return on investment through the US Investment Tax Credit, and sells power to the utility. A second scheme involves the pooling of debt for a great number of different renewable energy projects, and then selling bonds on this consolidated portfolio of projects. Solar power projects are especially attractive for these so-called "green bonds".

These financing schemes – however creative and useful they may be – nonetheless rely for their success on the assumed diligence of policy makers to create the appropriate background conditions for projects to be viable. So while investors may not need to concern themselves with transmission or transition problems, governments do. The need for appropriate policies does not change. The following sections discuss abiding policy needs to accelerate the uptake of renewable energy by 2030.

9.2 Policy framework and recommendations

This report discussed the current energy situation, existing policy framework and barriers to renewables in the US and identified the potential of renewable energy technology to nearly triple its energy share by 2030. Based on these findings, this section provides a list of policy recommendations in five areas. These areas of policy action are determined based on IRENA's analysis of 26 REmap countries and in consultation with the national experts, and they consist of the following: 1) establishing transition pathways for renewable energy, 2) creating an enabling business environment, 3) integrating renewable energy, 4) managing knowledge, and 5) unleashing innovation.

Planning transition pathways:

Setting national plans and targets and developing long-term strategies to support the growth of renewable energy use based on credible and attainable targets are the starting points for increasing the renewable energy share in any country. Various organizations in the US are already active in developing major energy use scenarios being used by various stakeholders. If these scenarios are continuously updated to reflect the rapid developments in renewable energy markets, in terms of technology development, innovation and costs, they would provide a strong baseline for the US to plan its transition pathway to 2030 and beyond.

There is large potential for all different types of renewable energy sources, in particular for biomass and also for renewable power generation from solar and wind. In fact, three-quarters of the US renewable energy use in REmap 2030 would come from wind and biomass when all REmap Options are implemented. Given the availability of other renewable energy resources, policies should ensure the deployment of all types of renewables to avoid technology lock-ins and accelerate the transition.

Based on the findings of this report, several recommendations emerge which are presented below. Although not discussed in great detail below, economic feasibility will be key factor in realizing the implementation of each recommendation during the transition period from today to 2030. Therefore these should be taken into account in formulating new policies.

Recommendations

- Reconsider the EIA forecasts for renewable energy (making upward revisions for wind, solar) and cost projections, taking into account the potential for energy efficiency improvements.
- Facilitate the use of DoE lab estimates that take into account the latest technology and cost information in energy planning.
- Reach consensus on the cost and benefits of accelerated renewables uptake, both from a business and from a macroeconomic perspective.
- Develop a national renewable power objective, along the lines of the biofuel objective, with special attention for solar and wind, which would accelerate already the rising share of renewable power generation to replace aging conventional power plant capacity.
- Diversify transport sector energy use with EVs and liquid biofuels, and put more emphasis on the development of cost-effective solutions for freight, aviation and shipping.
- Overcome the biofuel blendwall, improve the existing biofuel objectives for the transport sector continuously.
- Develop national objectives for renewable heating and cooling in the buildings and industry sectors which can be maintained for the long-term and make sure they are supported by financial incentives.
- Consider including renewable thermal energy sources in federal and state building energy codes and standards.
- Promote the use of non-biomass renewable technologies for heating which so far have limited market share in heating applications.
- Integrate renewable energy strategy into the US climate change mitigation strategy.

Creating an enabling business environment:

In order to support deployment and improve the cost-effectiveness of renewable energy technologies, national plans of the US should be supported with extended policy support and long-term commitment to improve the cost-effectiveness of renewable energy technologies (*e.g.,* removal of soft costs). For example, the SunShot initiative aims to reduce the soft costs of solar PV by at least 80% in compared to the 2010 levels (per watt), and also reducing its share in the total installed solar PV prices from about 50% to 35%-43% in the same time period (Ardani *et al.*, 2013). Modeling studies showed that achieving the SunShot targets could result in one-third of the total power generation to come from solar PV by reducing, the need for CCS, nuclear and replacing natural gas in western North America (Mileva *et al.*, 2013).

In uncertain policy environments, risks related to investments increase, and hence the costs of technologies. As noted above, establishing policy frameworks that create appropriate conditions for investment are crucial to increasing confidence of investors in implementing renewable energy technologies, even when creative financing options are available.

The pros and cons of distribution of subsidy support between renewables and conventional technologies as well as the continuity of support to maturing technologies are hotly discussed. Today, renewable and other clean energy sectors are often dependent on subsidies and policy support because of their higher costs (particularly in the special case of shale gas in the US, see also Table 6), perceived risks compared to mature fossil energy technologies, and a regulatory and financial institutional structure centered on conventional energy systems. Without such support, it is difficult for these technologies to gain a market share and increased man-

Box 6: US National Energy Goals, according to the US Department of Energy's Quadrennial Energy Review[21]

Economic Competitiveness: Energy infrastructure should enable the US, under a level playing field and fair and transparent market conditions, to produce goods and services which meet the test of international markets while simultaneously maintaining and expanding jobs and the real incomes of the American people over the longer term. Energy infrastructures should enable new architectures to stimulate energy efficiency, new economic transactions, and new consumer services.

Environmental Responsibility: Energy infrastructure systems should take into consideration a full accounting (on a lifecycle basis) of environmental costs and benefits in order to minimize their environmental footprint.

Energy Security: Energy Infrastructure should be minimally vulnerable to supply disruptions and should be able to mitigate impacts, including economic impacts of disruptions by recovering quickly or with use of reserve stocks. Energy security should support overall national security.

Desirable Characteristics in 2030:

1. **Minimal-environmental footprint.** Energy systems should be designed, constructed, operated and decommissioned in a manner that is low carbon, and with minimal impact to water quality and quantity; and minimize the land use footprint, impact on biological resources, and toxic emissions.
2. **Affordability.** Ensures system costs and needs are balanced with the ability of users to pay. (Note three potential balancing points: overall system costs, system needs/benefits, and system cost allocation). Also, estimating avoided costs can be more complex than for simple levelized costs – calculations require tools to simulate the operation of the power system with and without any project under consideration. Estimating social costs and benefits can be even more complex.
3. **Flexibility.** Energy infrastructure that accommodates change in response to new and/or unexpected internal or external system drivers (i.e., intermittent power). Sub-characteristics of flexibility included: – Extensibility. The ability to extend into new capabilities, beyond those required when the system first becomes operational. -Interoperability. The ability to interact and connect with a wide variety of systems and sub-systems both in and outside of the energy sector. -Optionality. Provides infrastructures or features of infrastructures that would allow users to maximize value under future unforeseen circumstances.
4. **Robustness.** A robust energy system will continue to perform its functions under diverse policies and market conditions, and has its operations only marginally affected by external or internal events (including intermittent power). Sub characteristics of robustness include: – Reliability, sturdy and dependable, not prone to breakdowns from internal causes (*e.g.,* due to component failures); – Resiliency. The ability to withstand small to moderate intermittent disturbances without loss of service, to maintain minimum service during severe disturbances, and to quickly return to normal service after a disturbance.
5. **Scalability.** Energy infrastructure should be able to be sized to meet a range of demand levels. Systems can be scalable by being replicable, modular, and/or enlargeable.
6. **Safety.** Energy systems should be designed, constructed, operated and decommissioned in a manner that reduces risks to life or health.

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[21] Text adapted from two presentations which can be found at http://cms.doe.gov/sites/prod/files/2014/03/f13/Mar2014EAC-Kenderdine.pdf and http://www.jisea.org/pdfs/2014_annual_meeting_pershing.pdf

ufacturing capacity to drive down costs and improve technology learning. In recent years subsidies have helped to improve the efficiency of technologies (*e.g.,* advanced batteries, solar panels) and created market support which has, for example, resulted in substantial reductions in the cost of wind and solar technologies.

However, in the US electricity markets solar and wind are not always cost-competitive (though they are becoming increasingly so) compared to power from cheap shale gas or coal (at least if external costs are not factored into the cost estimates).

Renewable cost-competitiveness needs to be improved further through deployment and innovation which can eventually lead to independence from subsidies. REmap 2030 provides a snapshot of cost competitiveness of renewable excluding subsidy (see Section 7.4) through the financial indicator of incremental system cost, and when factoring benefits from improved health and environment, renewables result in significant cost-savings to the energy system as a whole. However to get there this requires continued support until cost-competitiveness of different technologies are reached. This can be done by targeted support with reducing subsidy levels until technologies are mature and cost-competitive. When achieving this, investment certainty needs to be ensured and a diverse energy portfolio should be aimed at by avoiding technology lock-in. Similar subsidy support should also be phased out from mature energy sectors to ensure a competitive market in particular given they still receive much subsidy support as the US EIA (2011) estimates show. It should be noted, however, that moves are already being made to force greater internalization of external costs, particularly in the area of carbon-related emissions, which will raise the cost of conventional energy use.

Recommendations

- Develop policies which allow for more market certainty and provide investment certainty. Abolish PTC for well-established technologies such as for fossil fuel production today[21], and gradually to 2030 for wind and biomass as to ensure level playing field.
- Better account for the external costs related to human health and GHG emissions in fossil fuel pricing.
- Reduce the installed cost of solar PV and CSP, technologies which are currently lagging behind compared to other renewables, through innovative financing scheme and streamlining of planning process on state and local level. This will also help renewables which are other than wind and biomass to contribute to the power sector's fuel mix.

Ensuring smooth integration of renewables into the system:

Integrating the large amount of different renewable energy technologies in different sectors requires particular attention. Given the wide distribution of resources in the US and the varying distance of resources to locations of demand locations will require the deployment of enabling technologies in both the power and end-use markets.

In the case of the power sector, the share of variable renewable energy generation could reach 26% in the US according to REmap 2030. While such levels could be challenging to accommodate in some countries, as discussed earlier in the previous section, grid integration is often seen less of an issue for the US assuming that a significant transmission capacity can be built. Reaching the variable renewable energy shares in the US as quantified in this report will, however, require dramatic investments in new transmission capacity in a very short time period. Expanding transmission capacity is essential to deliver the renewable resources from remote areas to densely populated demand centers, to ensure the integration of variable energy sources and increase the transfer capacity of interconnections. Implementing all REmap Options would imply wind capacity growing by about 16 GW_e per year, requiring new transmission facilities, for which manufacturing capacity of equipment would need to grow at similar rates. Expanding transmission capacity will ideally be supported by shortening the current planning times from a decade or longer (largely due to right-of-way negotiations) to periods more consonant with construction of new renewable energy generation facilities (typically less than two years) (Jimison and White, 2013). Utilization of existing natural gas peakers and ramping them more, decentralized and diversified renewable energy capacity, and demand response are all other components of the solution as also discussed earlier in Section 7.5.

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[21] Speech Senator Ron Wyden, Chairman of US Senate Committee on Finance, 7 April 2014, New York. More information on the role of subsidies in the USA can be found in US EIA (2011), EESI (2014) and ELI (2011).

Increasing biomass demand in REmap 2030 will require more intensive utilization of the US supply potentials. Today, the US is one of the largest investors in advanced biofuel production capacity, but investments need to be accelerated in order to reach the demand estimates according to REmap 2030. Similarly, production of bioenergy products for heating also needs to be accelerated as it will play a key role in both the building and manufacturing sectors. In addition, US may continue to play an important role in the international bioenergy market. This increasing demand requires new strategy and policies to develop and deploy various types of biomass resources including forestry residues, excess regrowth, processing residues, forest products, food and beverage post-consumer waste, agricultural residues, notable from corn and finally energy crops. Optimal allocation of biomass resources should be promoted on the basis of most sustainable and cost-competitive applications in power generation, heating and as transport fuels. Moreover, bioenergy policies should be integrated with policies in the areas of resource (agriculture, land, water) and infrastructure (logistics, biomass conversion plants) to ensure sustainable sourcing and supply of biomass. Such integration can be greatly facilitated by the use of models assessing climate-land use-energy-water systems.

Recommendations

- Enhance the effectiveness of the electricity grid system with enabling technologies, including responsive load, energy storage, hydrogen fuel cell, waste heat and smart grid technologies.
- Strengthen interconnection capacity and upgrade grids in order to facilitate variable renewable energy integration.
- Reduce the lengthy and complex interconnection planning and approval procedures through more federal communication, and facilitate state-by-state approval for routing and siting transmission construction.
- Prioritize the transmission capacity investments for inter-regional lines that link balancing areas.
- Closely coordinate energy efficiency and renewable energy policies, as important synergies are possible in terms of efficiency measures that encourage renewables and renewables options that result in still higher efficiency.
- Closely coordinate agriculture, forestry and bioenergy policies as to ensure sufficient quantities and acceptable price for feedstocks while maintaining sustainability of supply.
- Assess the requirements and train the workforce to meet the future needs of the technology advancements and policy changes.

Creating and managing knowledge:

In terms of the deployment and potential of renewable energy, the US has extensive knowledge. Some of the renewable energy technologies such as the ocean technologies could still benefit from public awareness of their large potential. This could help to ensure that their deployment is also considered in the portfolio of technologies. Consumers of fuels for heat generation can also benefit from more awareness campaigns about the array of costs and benefits of renewable energy technologies to ensure that solar thermal, geothermal and heat pumps are deployed next to biomass-based technologies.

The US is already very active in developing and sharing knowledge about the sustainability of liquid biofuels with decision-makers and the scientific community, in particular through the modeling efforts for understanding the biofuel life cycle GHG emissions related to land use. These have been accounted for in the expanded RFS2 to categorize biofuels based on their emission profile. Continuing to generate knowledge for other bioenergy commodities and similar emission categorization for solid biofuel and biogas use in other markets should be the next steps.

Recommendations

- Establish and improve programmes to increase awareness and strengthen the capacity of manufacturers, installers and users,
- Assess and communicate the transmission expansion benefits to accelerate investments. Benefits of transmission include economics, linking balancing areas, reducing the local effects of total variability of renewables, loads and conventional generators by aggregating larger areas,
- Design renewable energy technologies from the point of view of product and service life-cycle environmental and sustainability impacts.
- Raise public acceptance of renewable energy and ensure dissemination of accurate information.

Unleashing innovation:

Innovation in new and existing technologies as well as in policy/finance schemes is necessary to develop and deploy cost-effective and efficient renewable energy technologies. Innovation will also ensure that the renewable energy share of the US would not slow down after 2030, but continue with the development and commercialization of breakthrough technologies. The Quadrennial Energy Review (QER) and the Quadrennial Technology Review (QTR) which are being prepared by the US Department of Energy aim to address the issues around technology development and deployment (US DoE, 2014b;c). These reviews focus on six particular strategies, namely: (i) increase fuel efficiency, (ii) electrify the vehicle fleet, (iii) deploy alternative hydrocarbon fuels, (iv) increase building efficiency, (v) modernize the grid, and (vi) deploy clean electricity.

The capital stock of the hydropower plants in the US is on average older than 50 years. This creates a large potential for upgrading the existing plants with new and efficient turbines without needing to invest in

Box 7: US renewable energy R&D: Shifting emphasis from invention to deployment

Over the 35-year period from the DoE's inception at the beginning of fiscal year 1978 through 2012, federal funding for renewable energy R&D amounted to about 17% of the energy R&D total, compared with 15% for energy efficiency, 25% for fossil, and 37% for nuclear (Sissine, 2012).

DoE R&D for energy efficiency and R&D amounts to USD 1.175 billion in 2014. This includes nearly USD 250 million for solar and biomass each, USD 88 million for wind and around USD 50 million for geothermal and water power. The requested budget for 2015 is 10-20% higher. There is also R&D sponsored by individual states. In comparison, General Electric alone spent USD 2.1 billion on energy infrastructure research in 2011 (all forms of energy) highlighting the importance of the private sector in energy related R&D.

In addition, in 2014 the DoE announced a USD 4 billion in loan guarantee program available to innovative renewable energy and efficient energy projects (US DoE, 2014d). The program is aimed at supporting market ready technologies.

ARPA-E, or Advanced Research Projects Agency-Energy is a US government agency that was set up in 2007 and is tasked with promoting and funding research and development of advanced energy technologies. It is modeled after the Defense Advanced Research Projects Agency (DARPA).

ARPA-E is intended to fund high-risk, high-reward research that might not otherwise be pursued because there is a relatively high risk of failure.

ARPA-E was created to fund energy technology projects that translate scientific discoveries and cutting-edge inventions into technological innovations, and accelerate technological advances in high-risk areas that industry is not likely to pursue independently. It does not fund minimal improvements to existing technologies; such technology is supported through existing DoE programs, such as those of the DoE Office of Energy Efficiency and Renewable Energy (EERE).

ARPA-E funding comes in relatively small amounts, typically USD 0.5-10 million per project. Government agencies, academia and private individuals can apply. Several rounds have been held dispersing grants typically up to USD 100 million each. 362 projects have received more than USD 900 million through ARPA-E's programs and open solicitations.

Twenty-two of the projects projects that have received about USD 95 million in federal funding have raised a collective USD 625 million in private-sector investment. And while venture investment is one way to measure success in the green technology field, it's far from the only one. Some ARPA-E grant-winning companies have done well raising venture capital funding and landing customers and partners on their own. Private sector leverage should be a priority for further expansion.

completely new infrastructure. Reservoirs without any turbines can also benefit from such retrofits.

Transport costs can increase the delivered costs of biofuels substantially especially with increasing transport distances as more resources are used. One way to reduce the additional costs from transportation is to convert biomass into high energy density products with pre-processing technologies such as torrefaction or pyrolysis.

Furthermore, currently almost all potential of renewables in the transport sector is related to road transportation. By contrast, an increasing share of transportation will be from aviation and although their shares will still be low, shipping and rail transport will also gain importance. However, no renewable energy alternative potential has been estimated in REmap 2030 for these applications.

Recommendations

- Continue to support public and private research, development and demonstration (RD&D) and deployment of breakthrough renewable energy technologies.
- Continue to develop biorefinery concepts that can utilize biomass for generation of power, heat, chemicals, materials and food. Integrate commercial-scale plant with a functioning biomass supply chain.
- Explore new solutions for expanded applications in freight transportation, aviation and shipping including algae.

The most important finding of this study is that – if fully implemented – the portfolio of renewable energy technologies selected according to REmap 2030 which could nearly triple the renewable energy share of US in its final energy mix from about 8% in 2010 to 27% by 2030, or more than double the share in 2030 compared to the Reference Case. Some of these technologies result in savings (*e.g.,* wind, utility PV), others require additional costs (*e.g.,* biomass pellets for heating in building and industry sectors). Some have very high additional potential (*e.g.,* solar thermal) and others relatively small.

Regardless of the cost or additional potential, tripling the renewable energy share between 2010 and 2030 requires the entire portfolio of technologies to be developed and deployed. Hence, promoting the use of all different renewable energy technologies, including transportation fuels, heating/cooling technologies, different power generation alternatives and others will be necessary to reach the levels of renewable energy share identified in this country roadmap. This will require massive investments. There are also a number of related technology-specific areas which require focus. The recommendations for new technology related policies are discussed below.

Solar PV and wind:

- Continue the development of stable and predictable federal tax and energy policies which have been successful in private sector growth.
- Create an investment and regulatory environment that will allow solar PV and wind capacity to be installed by 2030 on par with today's global installed capacity.
- Strengthen efforts for offshore wind along the East coast.
- Suggest Federal government to take leadership in improving the cost-competitiveness of solar heating and cooling technologies with financial incentives including tax credits, rebate/grant programs and renewable energy credits until they are mature and cost-competitive.

Solar heating and cooling:

- Accelerate deployment of solar water heaters in buildings and industry as existing conventional heat generation capacities are retired and in new building and industry plant investments.

Geothermal:

- Support technology development and initiative tax policy for the deployment of geothermal projects.
- Improve the efficiency of leasing and permitting efforts for federal public land where most geothermal power resources are located.

Hydro and ocean:

- Support research and development of environmental friendly turbines and new technologies.

- Existing hydro facilities to be upgraded with newer turbines and non-power dams can have power generation installed.
- Ensure funding and support for ocean technology development and testing.
- Accelerate decision making for efficient siting and permitting of ocean energy equipment.

Biomass:

- Recognize the importance of biomass as a reliable resource in various applications, including as a dispatchable power generation source, and ensure the development and deployment of sustainable biomass feedstocks which are truly carbon neutral.
- Consider stronger support for biogas digestion for power generation and CHP.
- Enhance the overall efficiency of black liquor use (higher power-to-heat ratios).
- Mandate road vehicle technology standards that require higher shares of biofuels. Mandate the gasoline retail infrastructure to handle E15. At the same time promote drop-in fuels such as butanol to circumvent the blending problem.
- Consider promotion of biomass and liquids exports.

Reaching a 27% renewable energy share by 2030 for the US is not an end-point. With innovation and technological learning, existing technologies will improve in efficiency and gain further economic viability, and breakthrough technologies of today will be commercialized. Technology deployment needs to account for the developments and continue to go beyond these levels by 2030 with new policies in place.

9.3 Relevance of REmap findings to climate change mitigation and discussion

The analysis shows that renewables have a significant potential in the US. Under the Remap Options they would account for over a quarter of the US total final energy consumption by 2030. This report also finds that implementing all REmap Options is cost-effective, especially when externalities are accounted for. One of the externalities related to fossil fuels assessed in this study is the reduction of CO_2 emissions, which is regarded as the major driver of climate change.

Renewables have significant climate change benefits because they emit no or very low GHG emissions compared to fossil fuels. As it was shown for the global REmap 2030 results, renewable energy and energy efficiency technologies together could result in emission reductions which would keep the concentration in the atmosphere from surpassing 450 ppm of CO_2, the level at which scientists believe that global warming can be kept within an increase of two degrees Celsius to avoid the most catastrophic consequences.

Climate change policy has been on the US agenda for nearly two decades. In June 2013, a new Climate Change Action Plan was launched. The plan has three pillars (White House, 2013a):

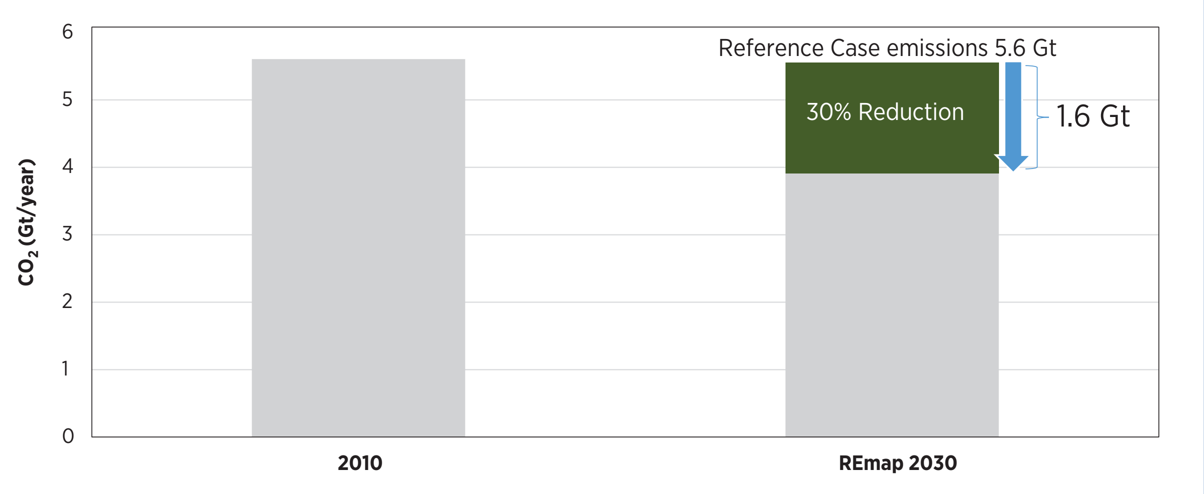
(i) Cutting carbon pollution in America,
(ii) Prepare the US for the impacts of climate change,
(iii) Lead international efforts to combat climate change and prepare for its impacts

The Climate Change Action Plan outlines different actions, some of which are related to the increased use of renewable energy, increasing the sustainability of the transport sector, and reducing non-CO_2 GHG emissions (White House, 2013a).

In May 2014, The United States Global Change Research Program (US GCRP) released its third National Climate Assessment (NCA). The report is a collaboration of federal agencies and many US experts. It focuses on the current and expected climate change impacts in the US, discusses the roles of different sectors regions and provides response strategies (US GCRP, 2014). According to the report, global warming, which is driven by human activity, is resulting in climate change impacts today and these impacts will continue in the future as well, including adverse effects on economy and quality of life. The report underlines that if the US is to avoid these impacts, existing plans for adapting to and mitigating climate change are currently insufficient and should be improved. According to the report, increased use of renewable energy is one of the different actions to available to reduce emissions.

According to Figure 31, increasing the share of renewables in TFEC of the US as detailed by REmap would

Figure 31: Reduction in fossil fuel CO_2 emissions resulting from REmap Options, 2030



reduce total fossil fuel combustion related emissions by up to 30% compared to both 2010 levels and the business as usual in 2030. Relative to 2005 levels, this is equivalent to a reduction of about 33%. These reductions are in line with the US commitment to reduce its greenhouse gas emissions by 17% in 2020 compared to 2005 levels (White House, 2013a) and the new pledges that aim to reduce US emissions by 26-28% by 2025 compared to the same base year. These emission reductions can be realized by implementing the realizable potentials of renewables.

Reductions in the US emissions would contribute to 19% of the global CO_2 emission reductions which would be achieved if all REmap Options required for doubling the global renewable energy share are implemented by 2030 (a total reduction of 8.6 Gt CO_2 emissions by 2030). Among the 26 REmap countries, the US has the second largest potential in terms of the absolute emission reduction volume following China. India is third. These three countries would account for half of the global emission reduction potential according to REmap 2030. Deployment of renewables and realizing the emission reductions in these countries are essential for a transition in the global energy system and to mitigate climate change.

These emission reduction estimates assume that all renewable energy sources are carbon-neutral. While this applies to most renewables, for biomass it is not the case because of the GHG emissions during bioenergy harvesting, processing and combustion, in particular when land use change emissions are accounted for. EPA has drafted a framework about the biogenic versus geologic carbon cycles of biomass related to their combustion in electricity generation. As of the beginning of June 2014, the framework is now being revised by EPA based on the feedback received from the Scientific Advisory Board (SAB) and other stakeholders. The framework, once finalized, will provide important information regarding the net atmospheric contribution of CO_2 emissions of biomass-derived fuels from their growth, harvesting and use. It may thus provide guidance for optimal development and deployment of sustainably sourced and truly carbon neutral biomass fuels.

In its liquid biofuel policy, the US has already responded to concerns about sustainability of biofuels by introducing emission savings standards coupled with volumetric targets. But more needs to be understood in the complex dynamic of bioenergy emissions accounting which is related to both emissions from combustion and land use change. These would also have large influence on the total emission reduction potentials of the US given that nearly 60% of the country's total renewable energy use comes from biofuels.

The third pillar of the Climate Change Action Plan addresses the international efforts in climate change and highlights in particular the importance of bilateral initiatives with China and India (White House, 2013a). Through these international efforts, the plan suggests that greater emission reductions can be achieved worldwide beyond 2020.

Renewables can play a key role in reducing global CO_2 emissions while avoiding gridlock

In June 2013, at the fifth round of the US-China Strategic and Economic Dialogue, China and the US agreed to work towards mitigating climate change based on a number of initiatives, including reducing vehicle emissions through improved fuel use efficiency standards and cleaner fuels and promoting smart grid technology. This is an important step towards the reduction of global GHG emissions as the two countries account for nearly half of the global GHG emissions (Freeman and Konschnik, 2014). In November 2014, the US together with China pledged GHG emission reduction targets. By 2025 the US plans to reduce its CO2 emissions by 26-28% compared to 2005 levels. These targets are similar to what has been envisioned in the 2009 American Clean Energy and Security Act and can be seen as an extrapolation of the reductions of 17% planned for the year 2020.

The US and India announced in June 2013 that they would establish a new Working Group on Climate Change building on the 2009 US-India Memorandum of Understanding (MoU) where the they agreed to cooperate on R&D of various technologies including renewable energy (Freeman and Konschnik, 2014).

As suggested by the Ad Hoc Working Group on the Durban Platform for Enhanced Action (ADP) which held its 4th part of its second session in March 2014 in Bonn, IRENA's REmap framework can be considered a useful tool in the context of climate change mitigation discussions, and can inform the debate about the role renewable energy can play in various countries. The ADP in particular highlights the importance of technology deployment, both in terms of energy efficiency and renewable energy, which is an area where the US, given its focus on technology, can play an important role.

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LIST OF ABBREVIATIONS

ACORE	American Council on Renewable Energy
ADP	Ad Hoc Working Group on the Durban Platform for Enhanced Action
AEO	Annual Energy Outlook
ARRA	American Reinvestment and Recovery Act
ARPA-E	Advanced Research Projects Agency- Energy
BCAP	Biomass Crop Assistance Program
BEV	battery-electric vehicle
BoE	barrel of oil equivalent
CAFÉ	Corporate Average Fuel Economy
CC	combined cycle
CCS	carbon capture and storage
CHP	combined heat and power
CO_2	carbon dioxide
CSP	concentrated solar power
DARPA	Defense Advanced Research Projects Agency
DoE	Department of Energy
DoS	Department of State
EIA	Energy Information Administration
EISA	Energy Independence and Security Act
EJ	exajoule
E.O.	Executive Order
EPA	Environmental Protection Agency
EU	European Union
EV	electric vehicle
FERC	Federal Energy Regulatory Commission
Gcal	gigacalories
GCRP	Global Change Research Program
GDP	gross domestic product
GHG	greenhouse gas
GJ	gigajoule
Gt	gigatonne
GW	gigawatt
GW_e	gigawatt-electric
GW_{th}	gigawatt-thermal
HEV	hybrid-electric vehicle
HHV	higher heating value
ICE	internal combustion engine
IEA	International Energy Agency
IGCC	integrated gasification combined cycle
IPCC	Intergovernmental Panel on Climate Change
IPP	independent power producer
IRENA	International Renewable Energy Agency
kt	kilotonne
kV	kilovolt
kW	kilowatt
kWh	kilowatt-hour
kW_e	kilowatt-electric
LCOE	levelised cost of electricity
LHV	lower heating value
LNG	liquefied natural gas
MATS	Mercury and Air Toxics Standard
MBtu	million British thermal units

MISO	Midwest Independent System Operator
MLP	master limited partnership
MoU	memorandum of understanding
Mt	megatonne
MW	megawatt
MWh	megawatt-hour
MW_e	megawatt-electric
MW_{th}	megawatt-thermal
NREL	National Renewable Energy Laboratory
NO_x	mono-nitrogen oxide
O&M	operation and maintenance
OECD	Organization for Economic Co-operation and Development
PHEV	plug-in hybrid electric vehicles
PJ	petajoule
PM	particulate matter
PTC	production tax credit
PURPA	Public Utility Regulatory Policy Act
PV	photovolatics
QER	Quadrennial Energy Review
QTR	Quadrennial Technology Review
REPI	Renewable Energy Production Incentive
RFS	Renewable Fuel Standard
RGGI	Regional Greenhouse Gas Initiative
RPS	Renewable Portfolio Standard
R&D	research and development
RD&D	research, development and deployment
SAB	Scientific Advisory Board
SE4All	Sustainable Energy for All
SO_2	sulphur dioxide
tcf	trillion cubic feet
TFC	total final consumption
TFEC	total final energy consumption
tce	tonnes of coal equivalent
toe	tonnes of oil equivalent
TPED	total primary energy demand
TWh	terawatt-hour
UN	United Nations
USA	United States of America
USD	US dollars
VETC	Volumetric Excise Tax Credits

ANNEX A:

Energy price assumptions

	Local energy prices in 2030
Crude oil (USD/GJ)	22.6
Steam coal (USD/GJ)	3
Electricity Household (USD/kWh)	0.15
Electricity Industry (USD/kWh)	0.09
Natural gas Household (USD/GJ)	15.5
Natural gas Industry (USD/GJ)	7.6
Petroleum products (USD/GJ)	34.0
Diesel (USD/GJ)	34.4
Gasoline (USD/GJ)	34.3
Kerosene (USD/GJ)	29.3
Biodiesel (USD/GJ)	34.4
Biofuel (USD/GJ)	30.1
First generation bioethanol (USD/GJ)	30.1
Second generation bioethanol (USD/GJ)	29.9
Biomethane (USD/GJ)	23.4
Biokerosene (USD/GJ)	32.8
Hydrogen (USD/GJ)	23.4
Primary biomass 1 (USD/GJ)	5.8
Primary biomass 2 (USD/GJ)	8.7
Primary biomass 3 (USD/GJ)	12.1
Biomass residues 1 (USD/GJ)	3.9
Biomass residues 2 (USD/GJ)	5.8
Biomass residues 3 (USD/GJ)	10.4
Traditional biomass 1 (USD/GJ)	3.3
Traditional biomass 2 (USD/GJ)	3.3
Municipal waste (USD/GJ)	1.1
Nuclear fuel (USD/GJ)	0.44
Carbon price (USD/t CO_2)	0
Interest rates for energy sector investment (%)	7.5
Discount rate (%)	7

ANNEX B:

Reference case

Sector	Renewable energy deployment in Reference Case in 2030	
Power sector (incl. CHP) (TWh/year)	Total electricity production	4 868
	Hydro	294
	Geothermal	42
	Solar PV	43
	CSP	3
	Wind	174
	Solid biomass	217
	Liquid & gaseous biofuels	22
	Solar thermal	
District Heat sector (incl. CHP) (PJ/year)	Total heat production	622
	Geothermal	
	Solid biomass	249
	Liquid & gaseous biofuels	9
	Solar thermal	
Industry (PJ/year)	Total consumption	19 539
	Electricity consumption	4 177
	Solid biomass	1 962
	Liquid & gaseous biofuels	
	Solar thermal	
Transport (PJ/year)	Total consumption	26 005
	Electricity consumption	47
	Liquid & gaseous biofuels	1 546
Buildings (PJ/year)	Total consumption	21 134
	Electricity consumption	11 168
	Solid biomass	573
	Liquid & gaseous biofuels	2
	Solar thermal	126

ANNEX C:

Data for cost-supply curve, from the business perspective and the government perspective

Business perspective

		PJ TFEC	Substitution cost (USD$_{2010}$/ GJ TFEC)
1	Autoproducers, CHP electricity part (solid biomass residues)	305	-15.7
2	Space heating: Pellet burners, substituting oil	203	-14.2
3	Landfill gas ICE	8	-13.1
4	Solar PV (Utility)	143	-12.8
5	Wind onshore	1358	-8.7
6	Solar PV (Utility), low solar irradiance	143	-7.3
7	Biomass boilers, residues	968	-3.4
8	Wind onshore, low wind resource	705	-2.0
9	Second generation bioethanol (passenger road vehicles)	1306	-2.0
10	Geothermal	442	-1.3
11	Autoproducers, CHP heat part (solid biomass residues)	1340	-1.0
12	Hydro, run-of-river	426	0.7
13	First generation bioethanol (passenger road vehicles)	238	1.1
14	Solar PV (Residential/Commercial)	45	1.1
15	Wind offshore	471	1.2
16	Space heating: Air-to-Air heat pumps	78	1.6
17	Solar CSP PT storage	16	1.7
18	Battery electric (passenger road vehicles)	22	1.8
19	Solar thermal, industry	241	1.9
20	Space heating: Solar (heat transfer fluid)	380	4.3
21	Biomass gasification	477	4.7
22	Water heating: Solar (heat transfer fluid)	89	5.2
23	Solar PV (Residential/Commercial), low solar irradiance	42	5.6
24	Hydrogen (passenger road vehicles)	196	5.8
25	Space heating: Geothermal heat pumps	78	7.7
26	Plug-in hybrid (passenger road vehicles)	137	8.9
27	Space Cooling: Solar	110	11.2
28	Biomass steam cycle	431	14.8
29	Plug-in hybrid (light-freight road vehicles)	67	18.0
30	Battery electric (light-freight road vehicles)	7	19.7
31	Hydrogen (freight road vehicles)	65	21.0

Government perspective

		PJ TFEC	Substitution cost (USD$_{2010}$/ GJ TFEC)
1	Autoproducers, CHP electricity part (solid biomass)	304	-15.0
2	Landfill gas ICE	8	-10.9
3	Solar PV (Utility)	143	-9.4
4	Wind onshore	1358	-7.4
5	Solar PV (Utility), low solar irradiance	143	-4.9
6	Biomass boilers	968	-4.4
7	Second generation bioethanol (passenger road vehicles)	1306	-1.8
8	First generation bioethanol (passenger road vehicles)	238	0.5
9	Wind onshore, low wind resource	705	0.8
10	Space heating: Pellet burners	203	0.9
11	Autoproducers, CHP heat part (solid biomass)	1336	1.3
12	Space heating: Air-to-Air heat pumps	78	2.0
13	Geothermal	442	2.1
14	Biomass gasification	477	3.3
15	Solar thermal	241	4.4
16	Solar PV (Residential/Commercial)	45	5.8
17	Wind offshore	471	6.2
18	Hydro, run-of-river	426	6.8
19	Solar CSP PT storage	16	7.4
20	Space heating: Solar (heat transfer fluid)	380	8.6
21	Space heating: Geothermal heat pumps	78	9.2
22	Water heating: Solar (heat transfer fluid)	89	9.5
23	Solar PV (Residential/Commercial), low solar irradiance	42	11.6
24	Space Cooling: Solar	110	17.6
25	Plug-in hybrid (passenger road vehicles)	137	20.3
26	Hydrogen (passenger road vehicles)	196	20.6
27	Battery electric (passenger road vehicles)	22	21.7
28	Biomass steam cycle	431	26.1
29	Plug-in hybrid (light-freight road vehicles)	67	29.7
30	Battery electric (light-freight road vehicles)	7	41.0
31	Hydrogen (freight road vehicles)	65	58.5

ANNEX D:

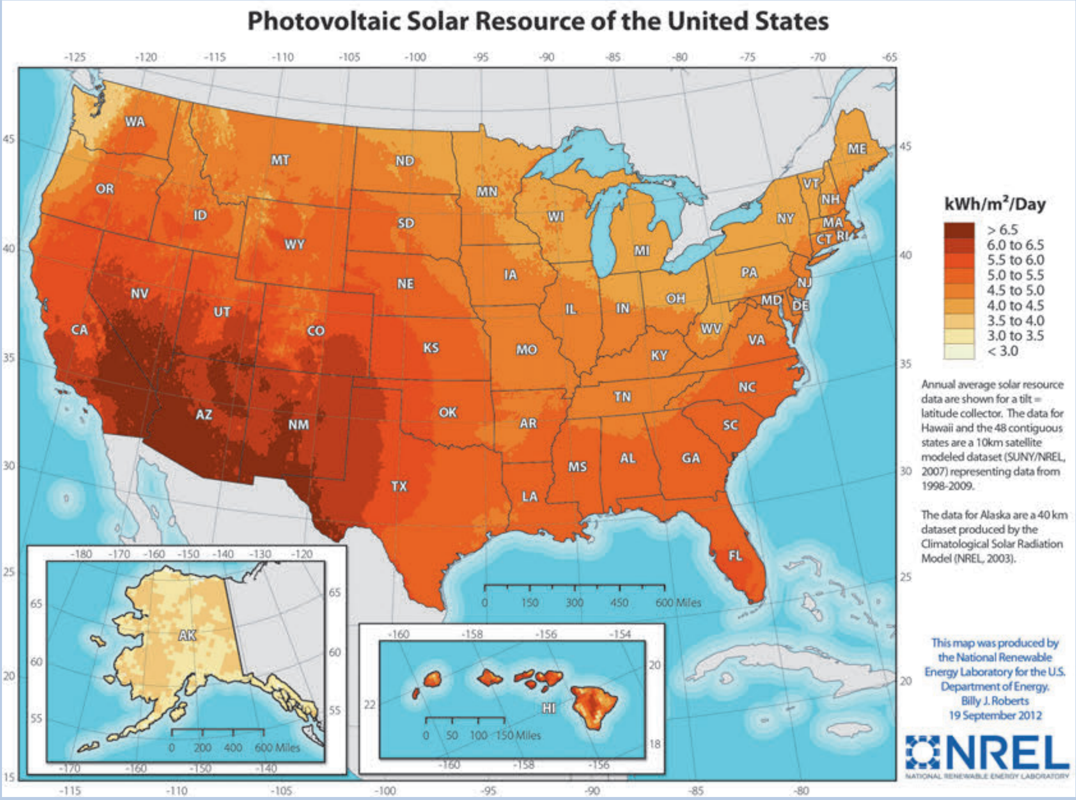
Levelized costs of renewable and conventional technologies in end-use sectors

		USD/GJ REmap 2030		USD/GJ REmap 2030
Industry	Autoproducers, CHP electricity part (solid biomass, residues)	9	Natural gas	10
	Autoproducers, CHP heat part (solid biomass, residues)	9	Natural gas (furnace)	13
	Solar thermal	14	Natural gas (steam boiler)	10
	Biomass boilers (residues)	8		
	Biomass gasification	15		
Buildings	Water heating: Solar (heat transfer fluid)	20	Space heating: natural gas (boiler)	9
	Space heating: Solar (heat transfer fluid)	20	Space heating: petroleum products (boiler)	41
	Space heating: Pellet burners	18	Space cooling: electricity	25
	Space heating: Geothermal heat pumps	25		
	Space heating: Air-to-Air heat pumps	19		
	Space Cooling: Solar	26		
		USD/p or t-km		**USD/p or t-km**
Transport	First generation bioethanol (passenger road vehicles)	0.47	Petroleum products (passenger road vehicles)	0.48
	Second generation bioethanol (passenger road vehicles)	0.47	Petroleum products (freight road vehicles)	0.23
	Hydrogen (passenger road vehicles)	0.48	Petroleum products (light-freight road vehicles)	0.23
	Hydrogen (freight road vehicles)	0.31		
	Plug-in hybrid (passenger road vehicles)	0.48		
	Plug-in hybrid (light-freight road vehicles)	0.26		
	Battery electric (passenger road vehicles)	0.48		
	Battery electric (light-freight road vehicles)	0.27		

ANNEX E:

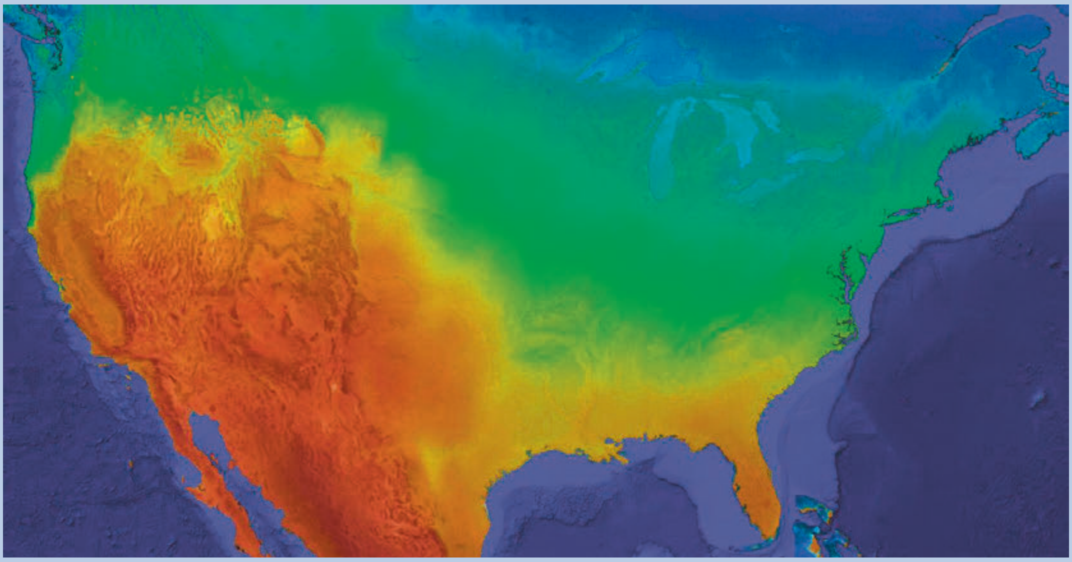
Resource maps

Figure 32: Photovoltaic solar resource



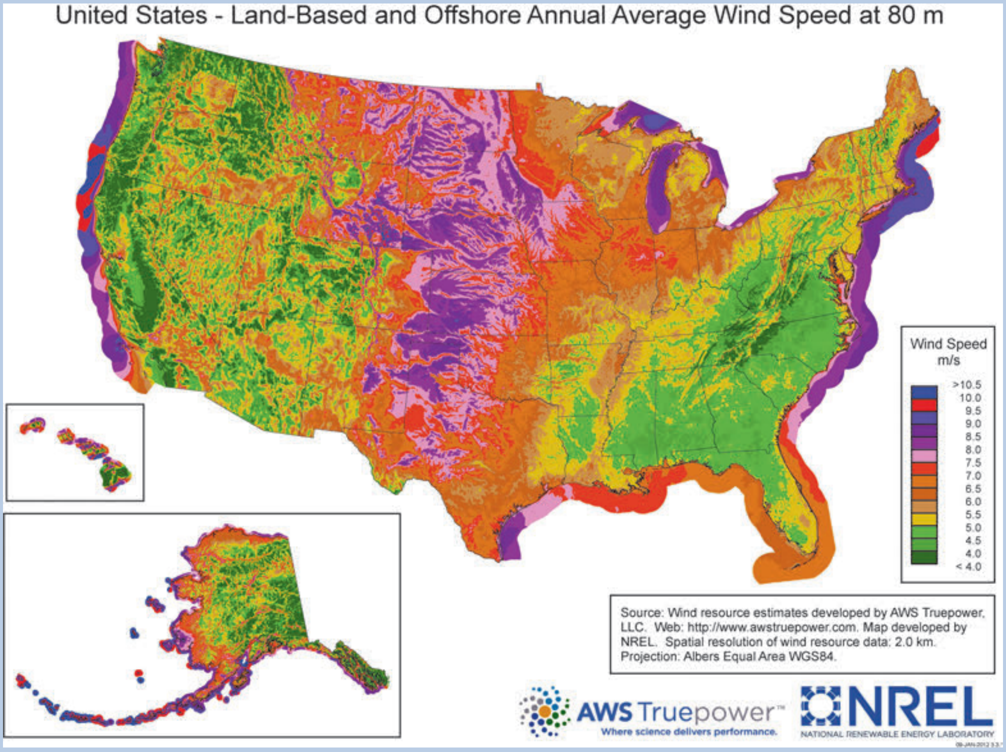
Source: NREL (2012b)

Figure 33: Solar PV resource intensity



Source: IRENA Global Atlas (3TIER) (IRENA, 2013b)

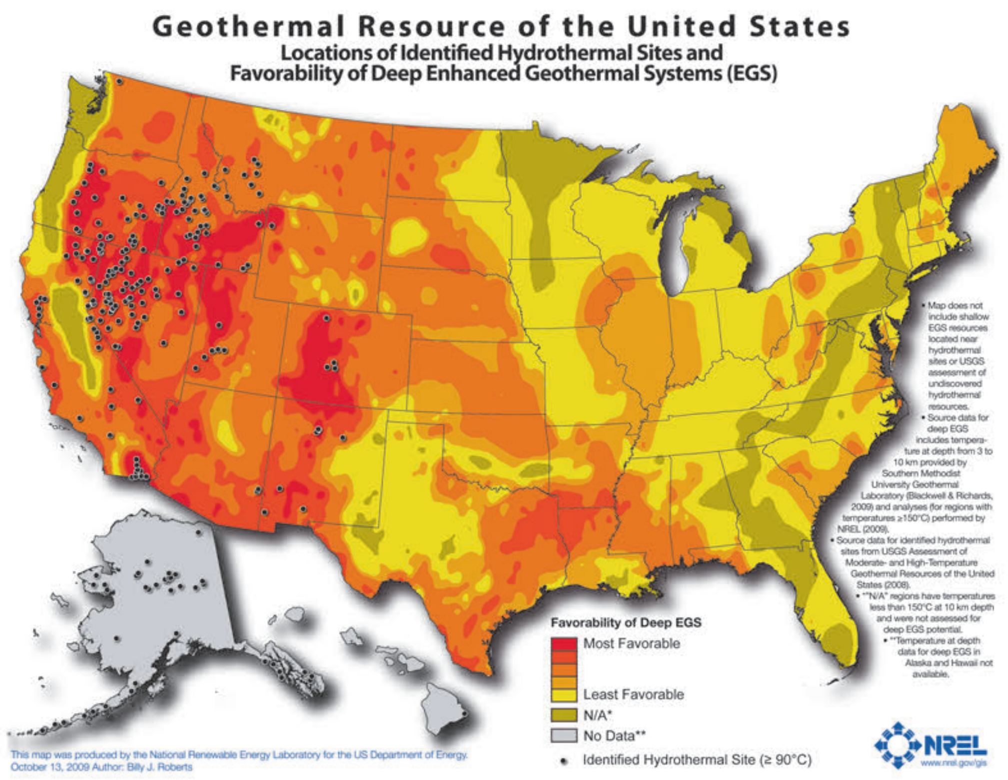
Figure 34: US wind speed


United States - Land-Based and Offshore Annual Average Wind Speed at 80 m

Source: Wind resource estimates developed by AWS Truepower, LLC. Web: http://www.awstruepower.com. Map developed by NREL. Spatial resolution of wind resource data: 2.0 km. Projection: Albers Equal Area WGS84.

Source: NREL (2012b)

Figure 35: Geothermal resource

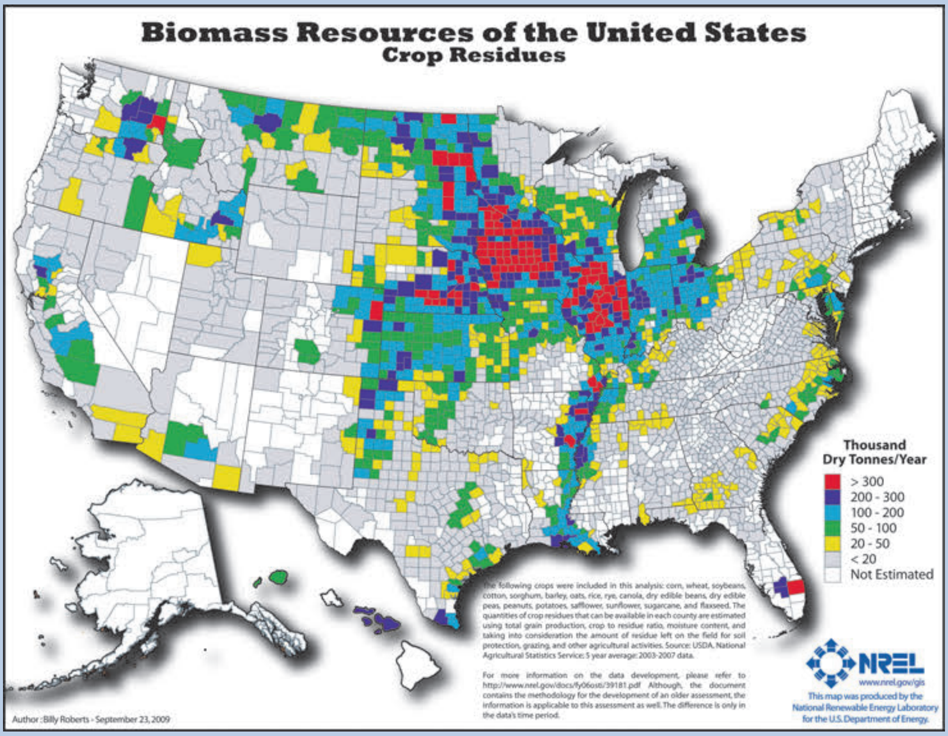

Geothermal Resource of the United States
Locations of Identified Hydrothermal Sites and Favorability of Deep Enhanced Geothermal Systems (EGS)

- Map does not include shallow EGS resources located near hydrothermal sites or USGS assessment of undiscovered hydrothermal resources.
- Source data for deep EGS includes temperature at depth from 3 to 10 km provided by Southern Methodist University Geothermal Laboratory (Blackwell & Richards, 2009) and analyses (for regions with temperatures ≥150°C) performed by NREL (2009).
- Source data for identified hydrothermal sites from USGS Assessment of Moderate- and High-Temperature Geothermal Resources of the United States (2008).
- *"N/A" regions have temperatures less than 150°C at 10 km depth and were not assessed for deep EGS potential.
- **Temperature at depth data for deep EGS in Alaska and Hawaii not available.

This map was produced by the National Renewable Energy Laboratory for the US Department of Energy. October 13, 2009 Author: Billy J. Roberts

Source: NREL (2012b)

Figure 36: Biomass crop residue potentials

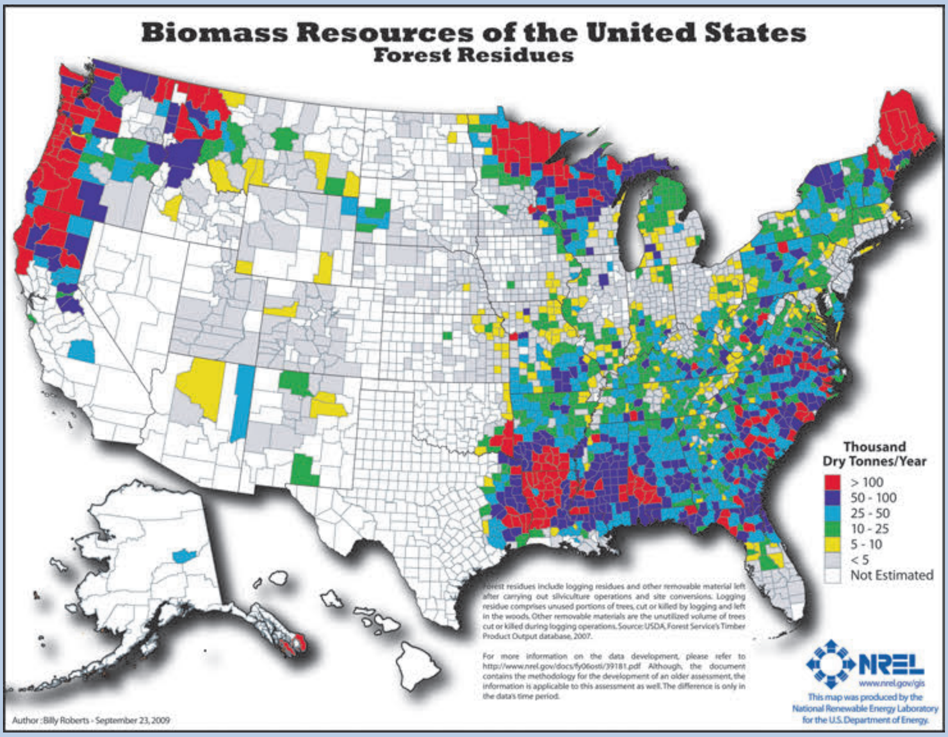


The following crops were included in this analysis: corn, wheat, soybeans, cotton, sorghum, barley, oats, rice, rye, canola, dry edible beans, dry edible peas, peanuts, potatoes, safflower, sunflower, sugarcane, and flaxseed. The quantities of crop residues that can be available in each county are estimated using total grain production, crop to residue ratio, moisture content, and taking into consideration the amount of residue left on the field for soil protection, grazing, and other agricultural activities. Source: USDA, National Agricultural Statistics Service; 5 year average: 2003-2007 data.

For more information on the data development, please refer to http://www.nrel.gov/docs/fy06osti/39181.pdf Although, the document contains the methodology for the development of an older assessment, the information is applicable to this assessment as well. The difference is only in the data's time period.

Source: NREL (2012b)

Figure 37: Biomass forest residues potential



Forest residues include logging residues and other removable material left after carrying out silviculture operations and site conversions. Logging residue comprises unused portions of trees, cut or killed by logging and left in the woods. Other removable materials are the unutilized volume of trees cut or killed during logging operations. Source: USDA, Forest Service's Timber Product Output database, 2007.

For more information on the data development, please refer to http://www.nrel.gov/docs/fy06osti/39181.pdf Although, the document contains the methodology for the development of an older assessment, the information is applicable to this assessment as well. The difference is only in the data's time period.

Source: NREL (2012b)

ANNEX F:

Detailed Roadmap Table

Total primary energy supply (PJ/year)	**2010**	**Reference 2030**	**REmap 2030**
Coal	21 045	20 401	8 469
Oil	31 365	29 360	26 618
Gas	22 862	25 575	20 384
Nuclear	8 905	10 090	7 828
Hydro	936	1 059	1 550
Traditional biomass	0	0	0
Modern bioenergy (incl. biogas, biofuels)	4 183	6 609	12 651
Solar thermal	100	137	675
Solar PV	13	155	847
Wind	344	625	4 153
Geothermal	551	1 537	2 955
Ocean / Tide / Wave / Other	0	0	0
Total	*90 303*	*95 547*	*86 124*
Total final energy consumption (PJ/year)			
Coal	1 468	1 458	1 458
Oil	30 956	29 040	26 297
Gas	14 700	16 301	11 219
Traditional biomass	0	0	0
Modern biomass (solid)	2 005	2 535	5 855
Modern biomass (liquid)	1 127	1 567	3 108
Solar thermal	96	126	996
Geothermal	11	25	25
Other renewables	0	0	261
Electricity	13 510	15 392	16 234
District Heat	278	234	234
Total	*64 150*	*66 678*	*65 688*
Gross electricity generation (TWh/year)			
Coal	1 847	1 765	638
Natural gas	969	1 377	1 361
Oil	37	18	18
Nuclear	806	914	707
Hydro	260	294	430
Biomass	95	238	490
Solar PV	4	43	235
CSP	1	3	8
Wind onshore	96	164	994
Wind offshore	0	9	160
Geothermal	15	42	183
Ocean / Tide / Wave	0	0	0
Total	*4 130*	*4 868*	*5 224*

Electricity capacity (GW)	**(2012)**		
Coal	333	284	103
Natural gas	365	480	474
Oil	61	7	7
Nuclear	102	124	96
Hydro (excl. pumped hydro)	78	79	114
Biomass	12	32	86
Solar PV (utility)	6	18	89
Solar PV (rooftop)	1.5	6	45
CSP	1	1	2
Wind onshore	60	61	314
Wind offshore	0	2	42
Geothermal	3	6	24
Ocean / Tide / Wave	0	0	0
Total	1 022	1 110	1 397
CO_2 emissions (Mt CO_2)			
Total emissions from fossil fuel combustion[23]	5 604	5 547	3 909
Renewable energy indicators (%)			
Renewable energy share electricity – generation	11%	16%	48%
VRE share electricity – generation	2%	5%	27%
Renewable energy share electricity – capacity	15%	19%	51%
VRE share electricity – capacity	7%	8%	35%
District heat – generation	20%	42%	42%
Industry	11%	13%	36%
incl. renewable energy electricity and DH	11%	14%	39%
Transport	4%	6%	13%
incl. renewable energy electricity and DH	4%	6%	14%
Buildings (excl. trad. biomass)	6%	7%	17%
incl. renewable energy electricity and DH	9%	12%	34%
TFEC	8%	10%	27.5%
TPES	7%	11%	27%
Financial Indicators (in USD_{2010})			
Substitution cost – Business Perspective (USD/GJ)			-0.9
Substitution cost – Government Perspective (USD/GJ)			2.0
Incremental system cost (bln USD/year)			13–20
Reduced human health externalities (bln USD/year)			-29 to -10
Reduced CO_2 externalities (bln USD/year)			-128 to -32
Incremental subsidy needs in 2030 (bln USD/year)			46
Incremental investment needs (bln USD/year)			38
Biomass Supply (PJ/year)			
Total supply potential			22 725
Total demand			16 080

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[23] Excluding other sectors, blast furnaces, coke ovens, non-energy use and others.

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