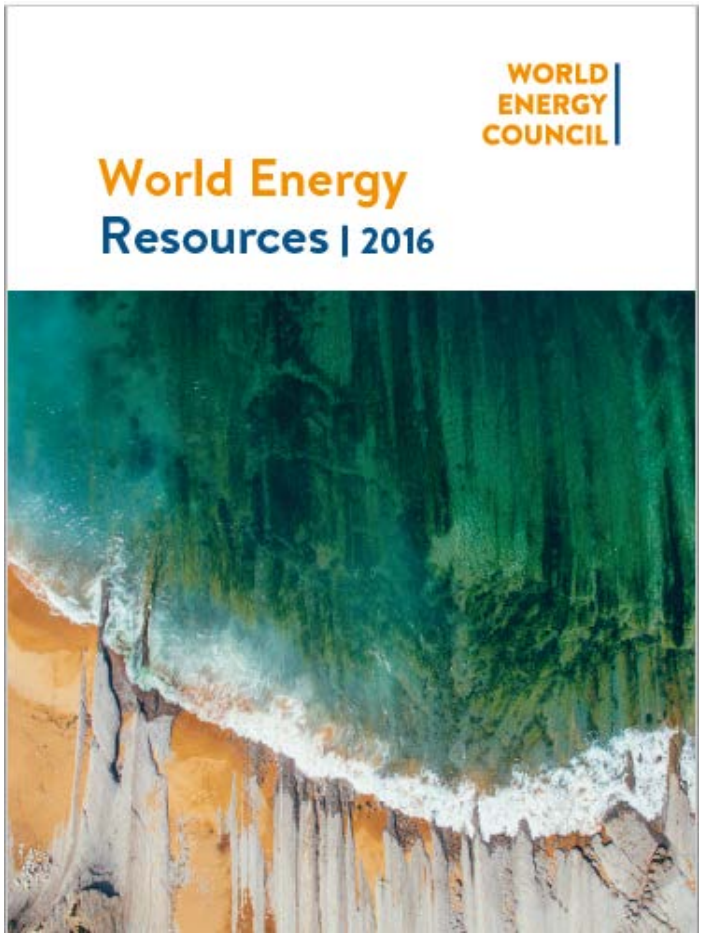
WORLD ENERGY COUNCIL

World Energy Resources

Summary Report

2016 World Energy Congress

World Energy Resources 2016



83 years since the first publication in 1933.

24th edition covers 12 energy resources, together with Carbon Capture and Storage (CCS) and energy-storage as two relevant technologies.

What has changed?

- The past 15 years have seen unprecedented change in the consumption of energy resources
- Unexpected high growth in the renewables market.
- Growth of unconventional resources
- Improvements in technology evolution for all the resources
- Decrease in energy prices
- Decoupling of economic growth and GHG emissions
- More diversified energy mix achieved
- Growth in community ownership and evolution of micro grids

An outlook over the past 15 years

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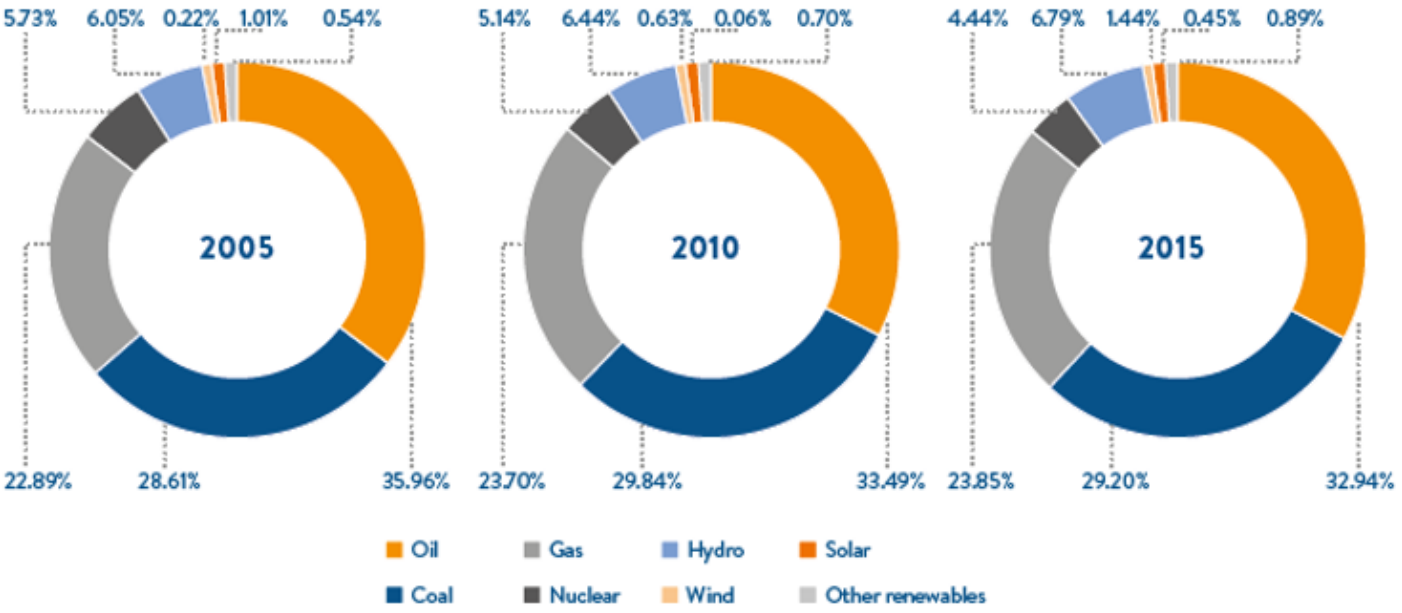
COMPARATIVE PRIMARY ENERGY CONSUMPTION OVER THE PAST 15 YEARS



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Coal

- The world currently consumes over 7 700 Mt of coal which is used by a variety of sectors including power generation, iron and steel production, cement manufacturing and as a liquid fuel.

- Coal currently fuels 40% of the world's electricity and is forecasted to continue to supply a strategic share over the next three decades. The tables below show the top coal producing countries and regions in the world for 2014 and 2015.

Top coal producing countries in 2014 and 2015

Million Tonnes	Production	
Country	**Total production 2014***	**Total production 2015****
Australia	503.3	485
China	4000	3747
Germany	186.5	184
India	659.6	677
Indonesia	470.8	392
Kazakhstan	115.6	106
Poland	136.9	136
Russia	357	373
South Africa	253.2	252
USA	906.9	813

Top coal producing regions in 2014 and 2015

Million Tonnes	Production	
Region	**Total production 2014***	**Total production 2015****
Total Africa	265.7	266
Total Asia Pacific	5 651.4	5440
Total CIS	544.8	527
Total EU	8 795.2	528
Total Middle East	2.8	1
Total North America	989.9	888
Total S. & Cent. America	103	98
World	8,176.4	7861

Key findings

1. Coal is the second most important energy source, covering 30% of global primary energy consumption. Hard coal and lignite (brown coal) is the leading energy source in power generation with 40% of globally generated power relying on this fuel.

2. Coal is predominantly an indigenous fuel, mined and used in the same country, allowing for security of supply where this is the case. The oversupply and price of natural gas have negatively impacted the coal industry.

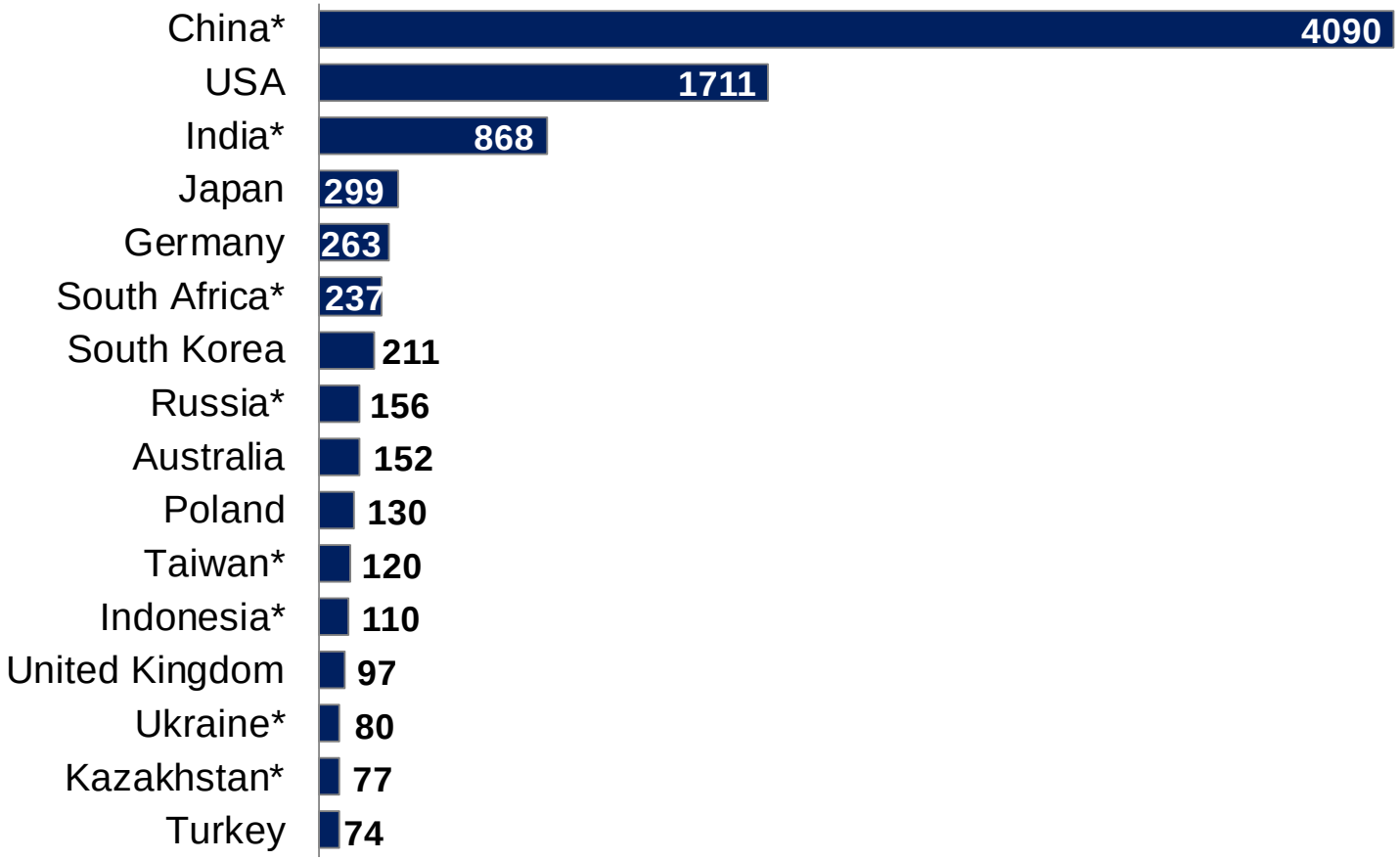
3. 75% of the global coal plants utilise subcritical technology. An increase in the efficiency of coal-fired power plants throughout the world from today's average of 33% to 40% could cut global carbon dioxide emissions by 1.7 billion tonnes each year.

4. Apart from the continued increase in the efficiency of power plants, the implementation of carbon capture utilisation and storage (CCUS) is one of the elementary strategies for climate protection.

5. Global coal consumption increased by 64% from 2000 to 2014. That classified coal as the fastest growing fuel in absolute numbers within the indicated period. 2014 and 2015 witnessed the first annual decrease in global thermal coal production of 0.7% and 2.8% respectively, since 1999.

6. China contributes 50% to global coal demand and is shifting to clean coal technologies. India's coal consumption is set to increase, while the US is closing or replacing coal with gas in power plants.

2014 Country ranking: coal-fired power generation (TWh)



Source: IEA, Electricity Information, Paris 2015 (*for Non-OECD-countries numbers for 2013)

Oil

- Oil remains the world's leading fuel, accounting for 32.9% of total global energy consumption. Although emerging economies continued to dominate the growth in global energy consumption, growth in these countries (+1.6%) was well below its ten-year average of 3.8%.

- Several structural changes are underway in the oil industry, the emergence of non-OPEC supply, the trends in energy efficiency, the diminishing role of high-sulphur oil with the environmental pressures in the marine fuel industry and in the power generation sector, the emergence of unconventional oil (shale oil, heavy oil, tight oil and tar sands), and increased production both from mature and frontier fields.

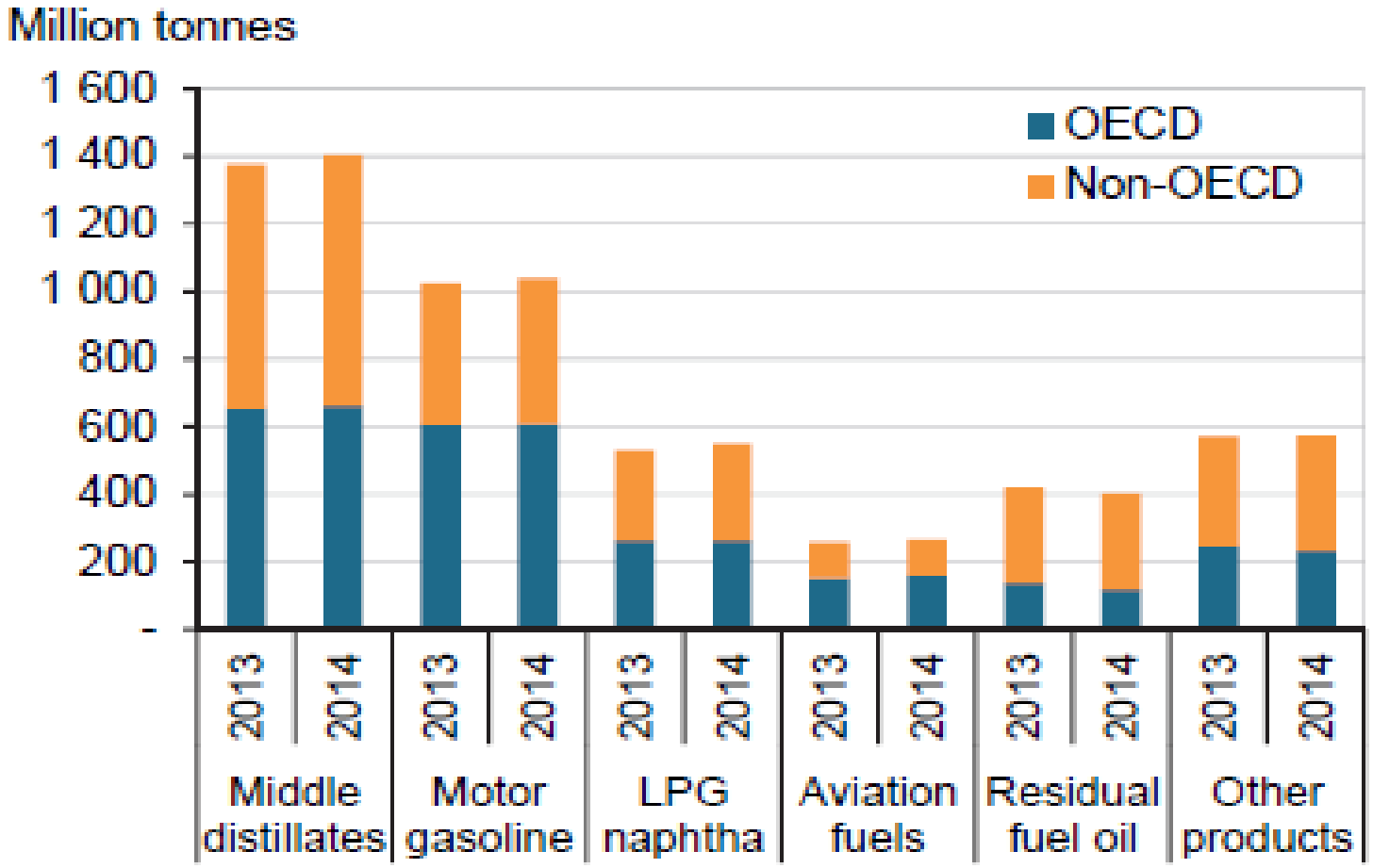
Global oil demand, by region from 2014-2020

	2014	2015	2016	2017	2018	2019	2020	2014-2020
OECD Americas	24.1	24.2	24.3	24.4	24.5	24.4	24.4	0.3
OECD Asia Ocean	8.1	8.0	7.9	7.9	7.9	7.9	7.8	-0.3
OECD Europe	13.4	13.3	13.3	13.2	13.1	13.0	12.9	-0.5
FSU	4.8	4.6	4.7	4.7	4.8	4.9	5.0	0.1
Other Europe	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.1
China	10.4	10.6	10.9	11.2	11.5	11.8	12.1	1.7
Other Asia	12.1	12.5	12.9	13.3	13.7	14.1	14.5	2.4
Latin America	6.8	6.9	7.0	7.1	7.2	7.3	7.4	0.6
Middle East	8.1	8.3	8.5	8.8	9.0	9.2	9.5	1.4
Africa	3.9	4.1	4.2	4.4	4.5	4.6	4.8	0.9
World	**92.4**	**93.3**	**94.5**	**95.7**	**96.9**	**98.0**	**99.1**	**6.6**

Key findings

1. Emerging economies now account for 58.1% of global energy consumption and global demand for liquid hydrocarbons will continue to grow. Chinese consumption growth slowed to 1.5%, while India (+5.2%) recorded another robust increase in consumption. OECD consumption increased slightly (+0.1%), compared with an average annual decline of 0.3% over the past decade. In 2015, a rare increase in EU consumption (+1.6%), offset declines in the US (-0.9%) and Japan (-1.2%), where consumption fell to the lowest level since 1991.
2. The growth of population and the consumer class in Asia will support oil demand increase and the main increase in consumption will come from transportation sectors.
3. Despite the temporary price drop, the fundamentals of the oil industry remain strong. Price fluctuations seen of late have been neither unexpected nor unprecedented.
4. The main drivers of price changes have been the gradual building up of OPEC spare capacity and the emergence of non-OPEC production, especially US Light Tight Oil (LTO). Substitution of oil in the transport sector is not yet imminent and is not expected to reach more than 5% for the next five years.
5. New and increased use of technologies such as high-pressure, high-temperature (HPHT) drilling; multi-stage fracking; development in flow assurance for mature fields; greater sophistication in well simulation techniques, reservoirs modelling; 3-D seismic technologies, EOR developments are having a positive impact on safety and E&P possibilities.

Product-market consumption trends



Natural gas

- Natural gas is the only fossil fuel whose share of the primary energy mix is expected to grow and has the potential to play an important role in the world's transition to a cleaner, more affordable and secure energy future. It is the number three fuel, reflecting 24% of global primary energy, and it is the second energy source in power generation, representing a 22% share.

- Advances in supply side technologies have changed the supply landscape and created new prospects for affordable and secure supplies of natural gas. Natural gas markets are becoming more interconnected as a result of gas-to-gas pricing, short-term trade and consumer bargaining power. The future of demand is highly uncertain, new policy frameworks and continued cost improvements will be needed to make gas more competitive. Infrastructure build out, government support and the closure of regulatory gaps are needed to unlock the socioeconomic and environmental benefits of natural gas

Regional natural gas data by region

2015	Proved Reserves		Production		R/P Ratio
Region	Bcm	Bcf	Bcm	Bcf	Years
Africa Total	14064	496666.5	211.8	7479.2	66.4
Asia Pacific Total	15648.1	552607.7	556.7	19658.2	28.1
Europe & Eurasia Total	56778.4	2005109.3	989.8	34955.2	57.4
LAC Total	7591.5	268091.0	178.5	6302.1	42.5
Middle East Total	80040.9	2826617.7	617.9	21821.1	129.5
North America Total	12751.8	450326.0	984.0	34750.4	13.0
Global Total	186874.7	6599418.0	3538.6	124966.2	52.8

Key findings

1. Demand projections for natural gas exports to Asia, particularly China and Japan, have been revised down as importing nations push to improve energy security and reduce the impact of volatile commodity markets on domestic energy prices.
2. In particular, unconventional gas, shale and CBM, reflected more than 10% of global gas production in 2014 and is entering global markets as LNG, disrupting the global supplier landscape and creating increased competition in regional natural gas markets.
3. The shifting dynamics in natural gas pricing in recent years can be attributed to regional supply and demand imbalances. North America prices collapsed in 2009, driven by a domestic oversupply, while from 2011-2013, the Japanese nuclear drove prices higher in Asia.
4. Currently, the fall in demand in Asia and growing export capacity in Asia and North America, have created an oversupply globally. As further supplies come to the market, it appears likely that the current market oversupply and low price environment will continue in the short to medium-term.

New supply landscape (technically recoverable reserves)

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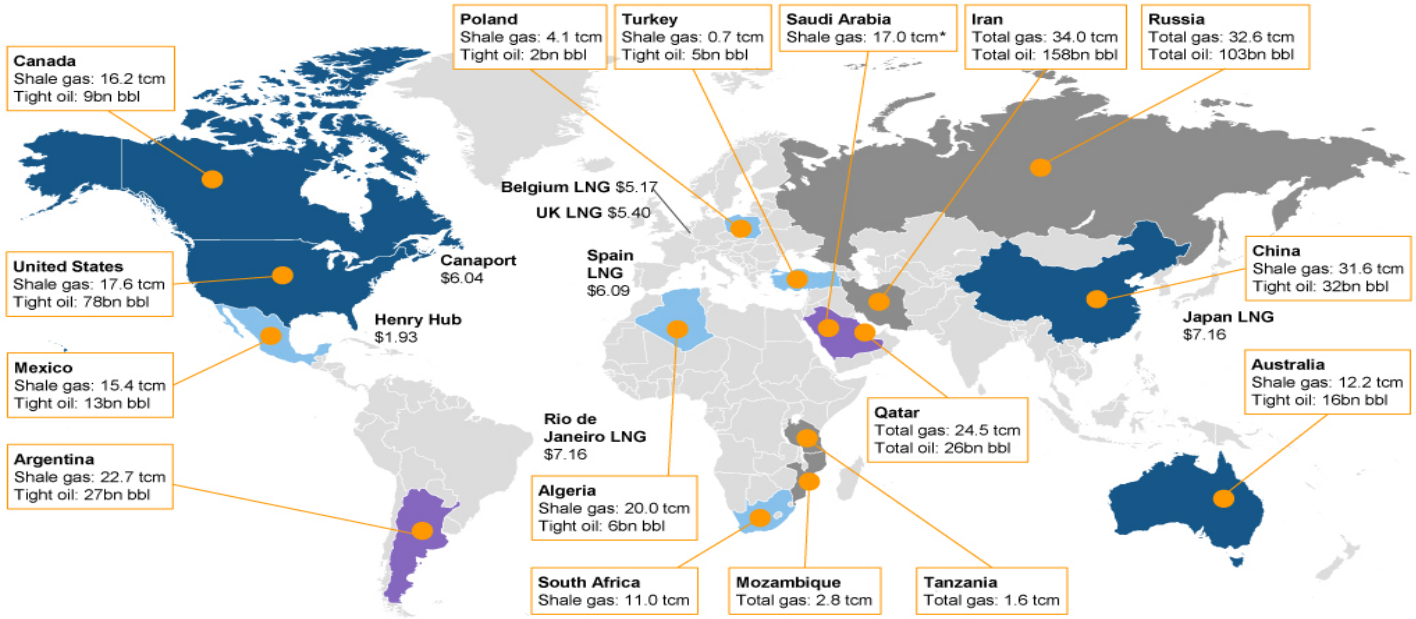
Unconventional gas, a global phenomenon

Despite the uncertain price environment, unconventional gas has become a global phenomenon with new supplies coming from Australia, China and New Frontier countries.



Source: BP Statistical Review of World Energy, EIA, FERC, and Reuters

Sources: BP Statistical Review of World Energy, EIA, FERC, and Reuters

Uranium and nuclear

- The Fukushima accident in March 2011 resulted in a developmental hiatus and a nuclear retreat in some countries. However, with the benefit of five years of hindsight, the true proportions of that accident are becoming clearer: a barely perceptible direct impact on public health, but high economic and social costs.
- The assessments of global uranium resources show that total identified resources have grown by about 70% over the last ten years. As of January 2015 the total identified resources of uranium are considered sufficient for over 100 years' of supply based on current requirements.
- The development of nuclear power is today concentrated in a relatively small group of countries. China, Korea, India and Russia account for 40 of the 65 reactors that the IAEA records as under construction in December 2015. The countries that have historically accounted for the majority of nuclear power development are now under-represented in new construction. Currently there are more than 45 Small Modular Reactors designs under development and four reactors under construction.

Uranium production and resources

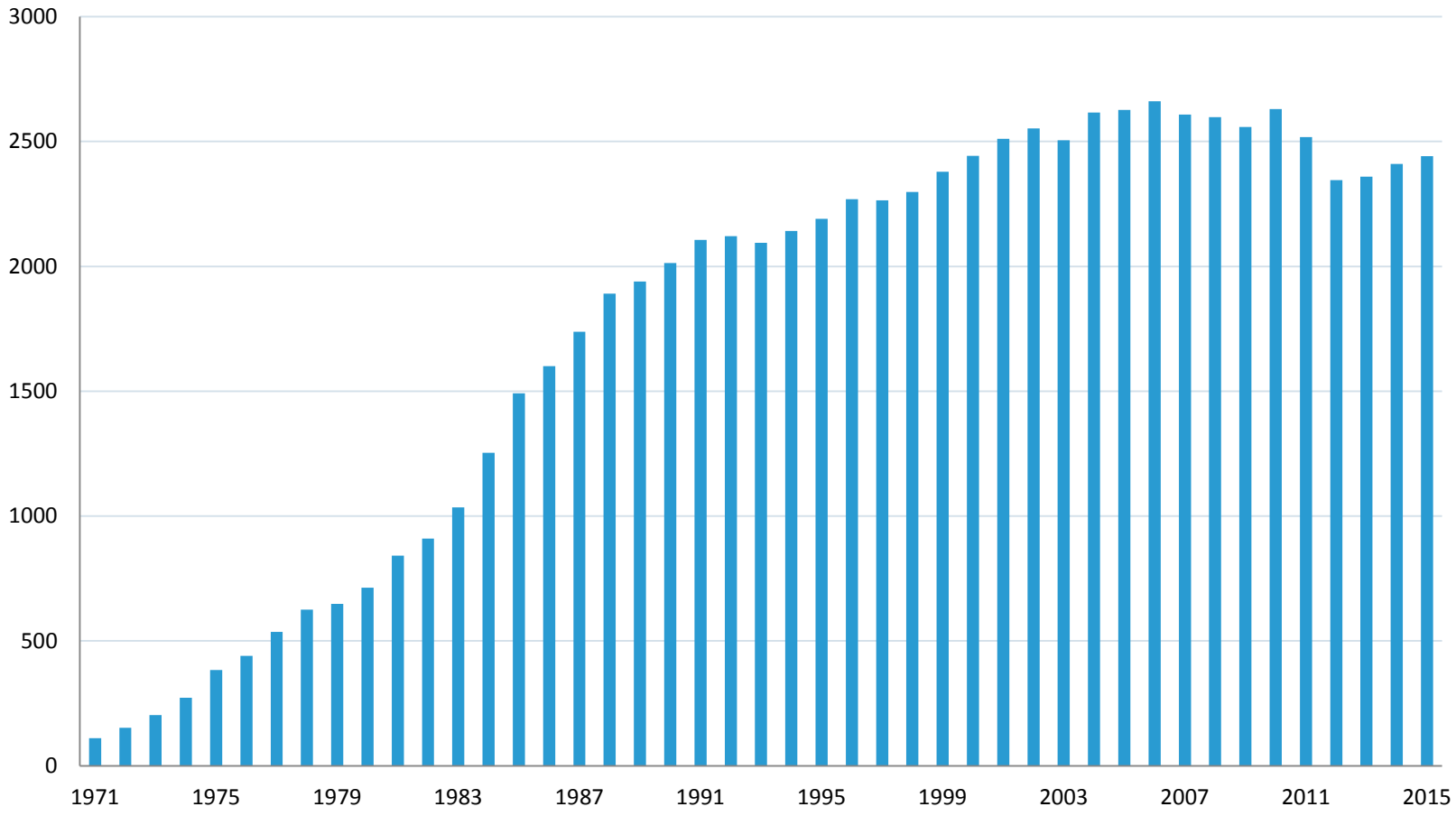
Country	2014 Production tU	Uranium resources (tU)<US$130/Kg
Australia	5001	1174000
Canada	9134	357500
China	1500	120000
Kazakhstan	23127	285600
Namibia	3255	248200
Niger	4057	325000
Russia	2990	216500
USA	1919	207400
Uzbekistan	2400	59400
Total	**56252**	**3698900**

Source: "Uranium 2014: Resources, Production and Demand" OECD-NEA & IAEA, 2014. Uranium: From Mine to Mill, World Nuclear Association, 2015

Key findings

1. Global nuclear power capacity reached 390 GWe at the end of 2015, generating about 11% of the world electricity. As of December 2015, 65 reactors were under construction (6 more than in July 2012) with a total generating capacity of 64 GW.
2. The key drivers and market players defining the future of nuclear power are different from those 20-30 years ago and the emerging non-OECD economies (mainly China and India) are expected to dominate future prospects. The increasing need to moderate the local pollution effects of fossil fuel use, means that nuclear is increasingly seen as a means to add large scale baseload power generation while limiting the amount of GHG emissions.
3. The low share of fuel cost in total generating costs makes nuclear the lowest-cost baseload electricity supply option in many markets. Uranium costs account for only about 5% of total generating costs and thus protect plant operators against resource price volatility. Generation IV reactors promise to remove any future limitation on fuel supply for hundreds of years.
4. Nuclear desalination has been demonstrated to be a viable option to meet the growing demand for potable water around the globe, providing hope to areas in arid and semi-arid zones that face acute water shortages.

World nuclear electricity production, TWH



Source: International Atomic Energy Agency, Power Reactor Information System

Hydropower

- There has been a major upsurge in hydropower development globally in recent years. The total installed capacity has grown by 39% from 2005 to 2015, with an average growth rate of nearly 4% per year. The rise has been concentrated in emerging markets where hydropower offers not only clean energy, but also provides water services, energy security and facilitates regional cooperation and economic development.
- It is estimated that 99% of the world's electricity storage capacity is in the form of hydropower, including pumped storage and provides an array of energy services beyond power, including black start capability, frequency regulation, inertial response, spinning and non-spinning reserve and voltage support, which are increasingly important to the stability of the energy system.
- Technological innovation in hydropower include: a) increasing the scale of turbines (1000 MW turbine in development), b) advanced hydropower control technologies that enable renewable hybrids, c) both conventional and pumped storage hydropower increasingly utilised as a flexible resource for balancing variable renewable resources.

Top hydropower capacity as of 2015

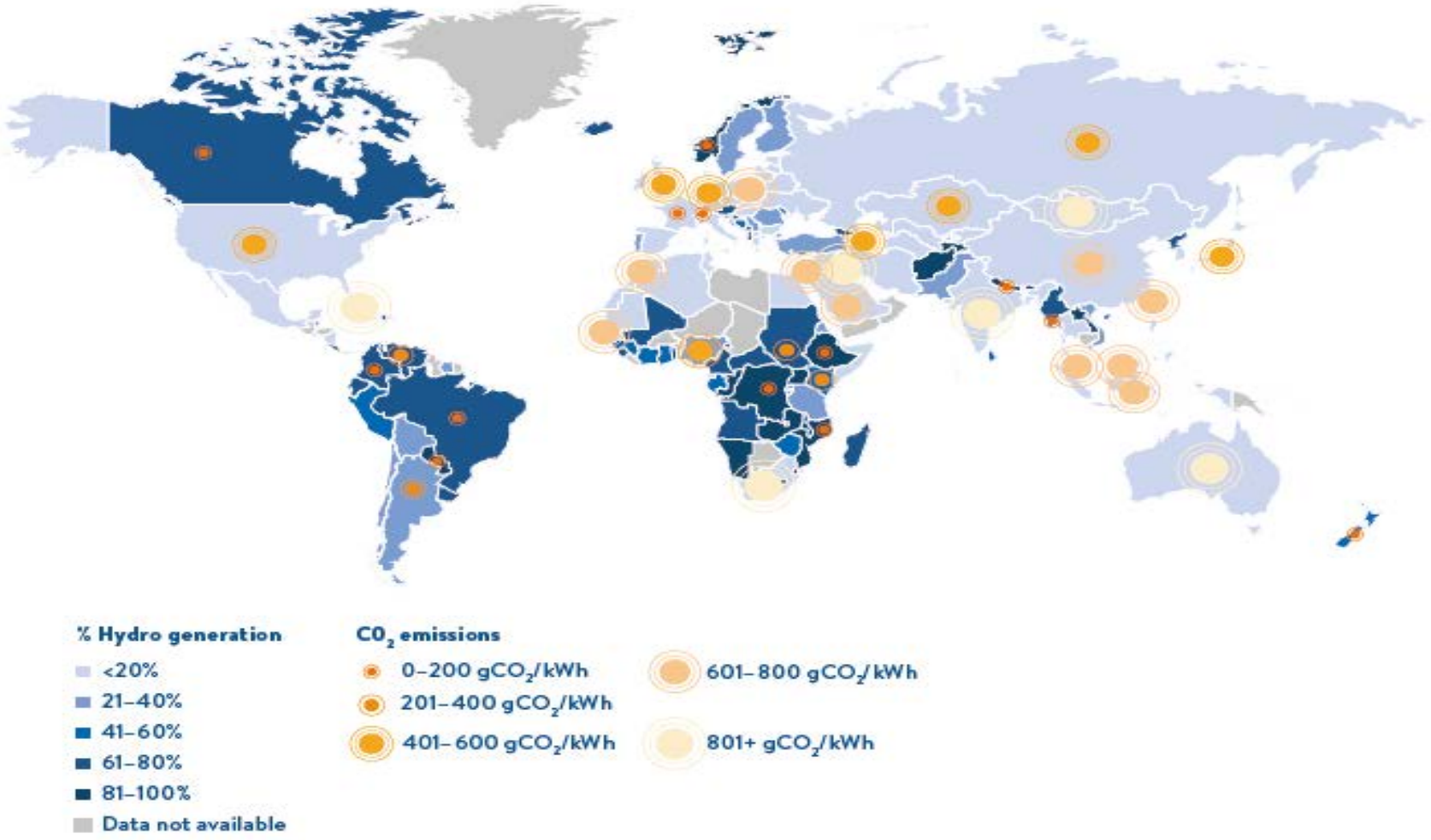
	Total Capacity end of 2015 (GW)	Added Capacity in 2015 (GW)	Production (TWh)
China	319	19	1,126
USA	102	0.1	250
Brazil	92	2.5	382
Canada	79	0.7	376
India	52	1.9	120
Russia	51	0.2	160

Source: REN21, IHA (2015)

Key findings

1. Hydropower is the leading renewable source for electricity generation globally, supplying 71% of all renewable electricity. Reaching 1 064 GW of installed capacity in 2016, it generated 16.4% of the world's electricity from all sources.
2. Significant new development is concentrated in China, Latin America and Africa. Asia has the largest unutilised potential, estimated at 7 195 TWh/y, making it the likely leading market for future development. China accounted for 26% of the global installed capacity in 2015, far ahead of USA (8.4%), Brazil (7.6%) and Canada (6.5%).
3. As hydropower has good synergies with all generation technologies, its role is expected to increase in importance in the electricity systems of the future. This is especially true of pumped hydro used as storage, but also increasingly to balance the volatility caused by increased renewable energy in the system.
4. Consideration of water management benefits offered by hydropower facilities includes flood control, water conservation during droughts or arid seasons.

The contribution of hydropower to a low carbon future



Bioenergy

- The World Energy Council defines bioenergy to include traditional biomass (example forestry and agricultural residues), modern biomass and biofuels. It represents the transformation of organic matter into a source of energy, whether it is collected from natural surroundings or specifically grown for the purpose.
- In developed countries, bioenergy is promoted as an alternative or more sustainable source for hydrocarbons, especially for transportation fuels, like bioethanol and biodiesel, the use of wood in combined heat and power generation and residential heating.
- There are multiple challenges and opportunities for bioenergy as a potential driver of sustainable development, given enough economic and technological support
- Global ethanol and biodiesel production are both expected to expand to reach respectively, almost 134.5 and 39 billion litres by 2024. Subsequently, both ethanol and biodiesel prices are expected to recover in nominal terms close to their 2014 levels

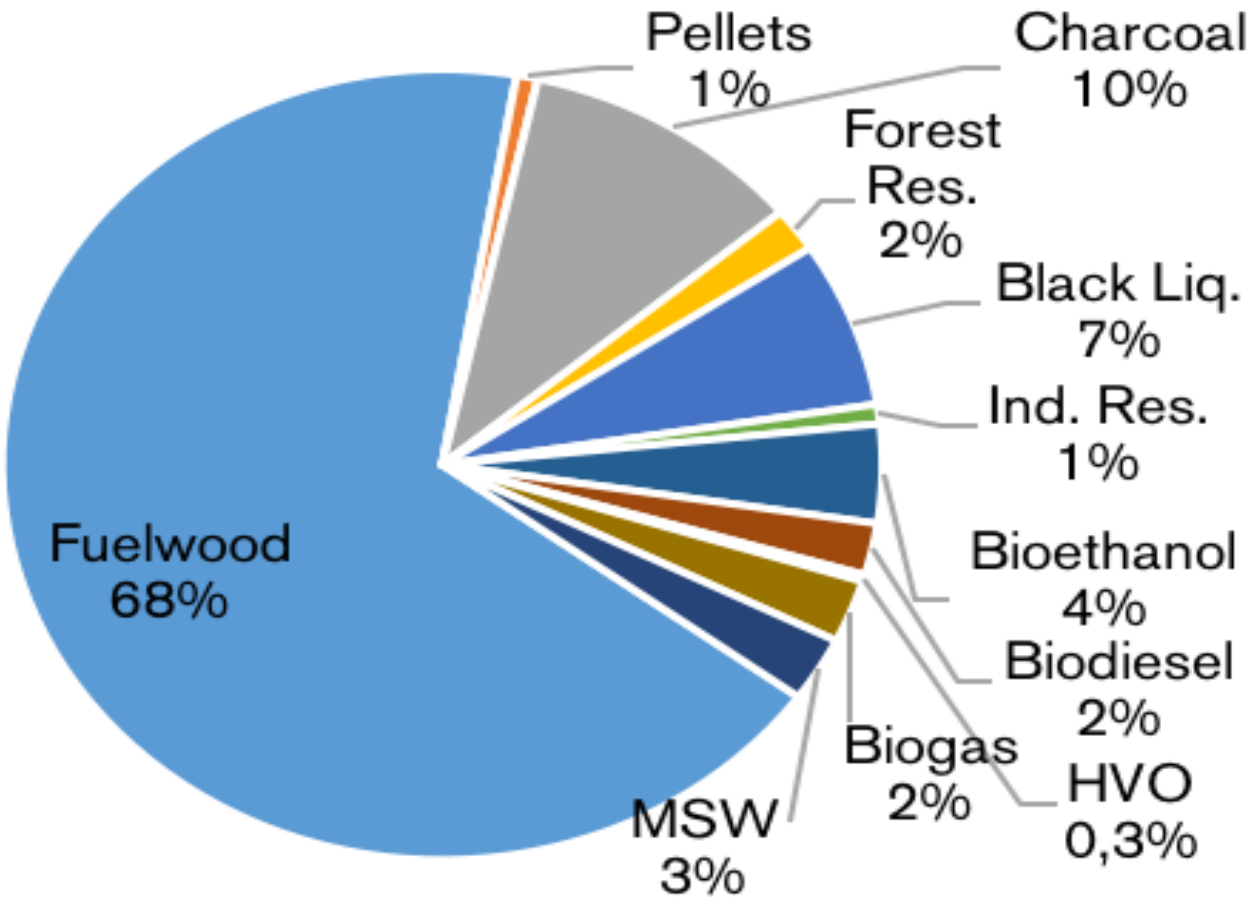
Share of biofuels production by region

Region	Percentage			
	1993	2003	2013	2014
Asia Pacific		3.3%	9.5%	10.5%
Africa				1.0%
Middle East				
Europe & Eurasia	1.1%	11.1%	17.1%	16.5%
S. & Cent. America	71.4%	49.2%	28.5%	28.7%
North America	27.4%	36.4%	44.8%	44.1%

Key findings

1. Bioenergy is the largest renewable energy source with 14% out of 18% renewables in the energy mix and supplying 10% of global energy supply. In contrast to other energy sources, biomass can be converted into solid, liquid and gaseous fuels.
2. It is shifting from a traditional and indigenous energy source to a modern and globally traded commodity. The consumption pattern varies geographically with biofuels in being dominant in the Americas, fuel wood and charcoal in Asia and Africa and combined heat and power generation in Europe.
3. The primary energy supply of forest biomass used worldwide is estimated at about 56 EJ and overall woody biomass provides about 90% of the primary energy annually sourced from all forms of biomass. Wood is also the source of more than 52 million tonnes of charcoal used in cooking in many countries, and for smelting of iron and other metal ores.
4. International trade is driven by pellets (27 million tonnes in 2015) and liquid biofuels.
5. With biofuels being the most viable and sustainable option in replacing oil dependency, future demand will come from the need for renewables in transport, followed by heating and electricity sectors.

Primary energy supply of biomass resources globally in 2013

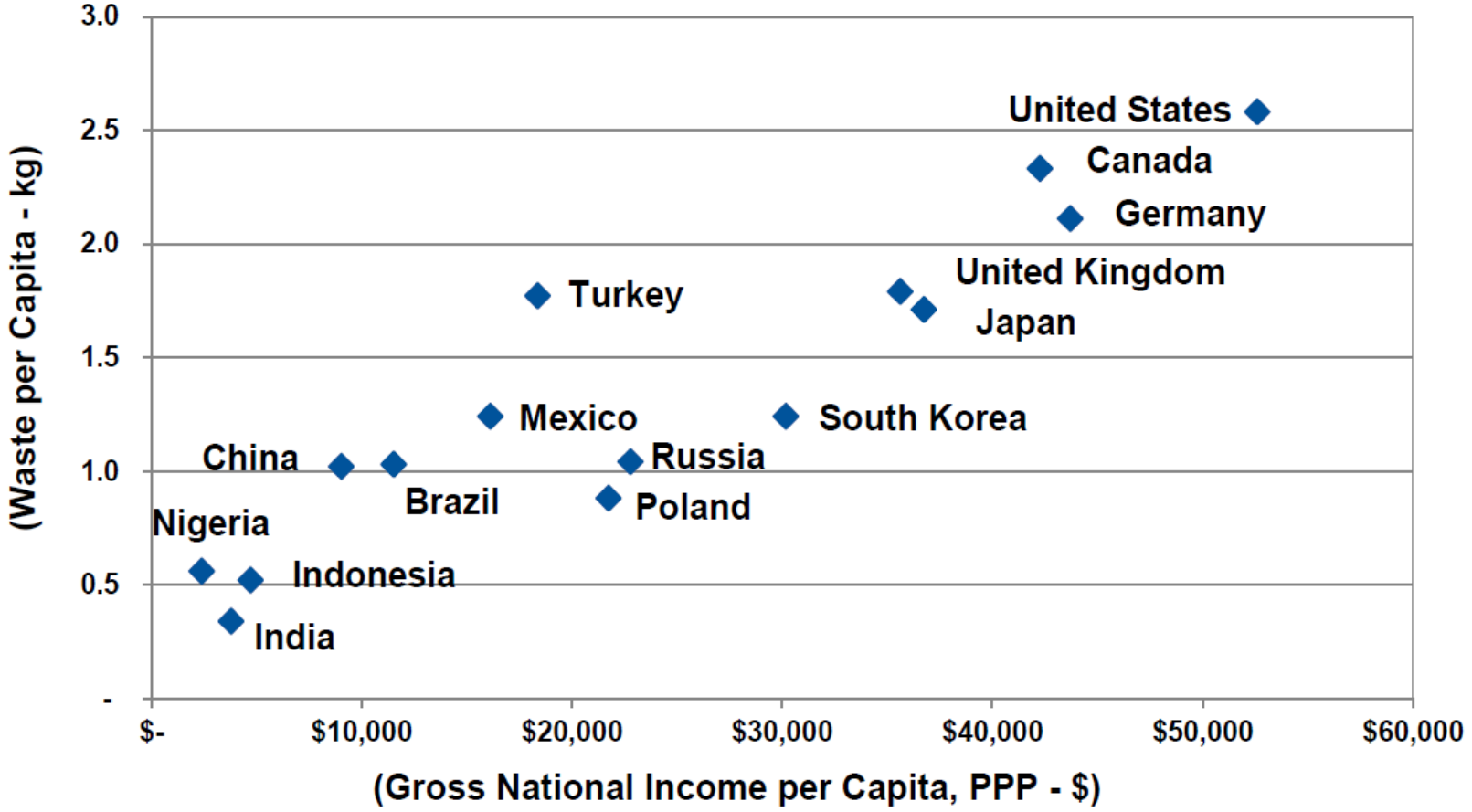


Source: Based on data from World Bioenergy Association (2016)

Waste-to-Energy

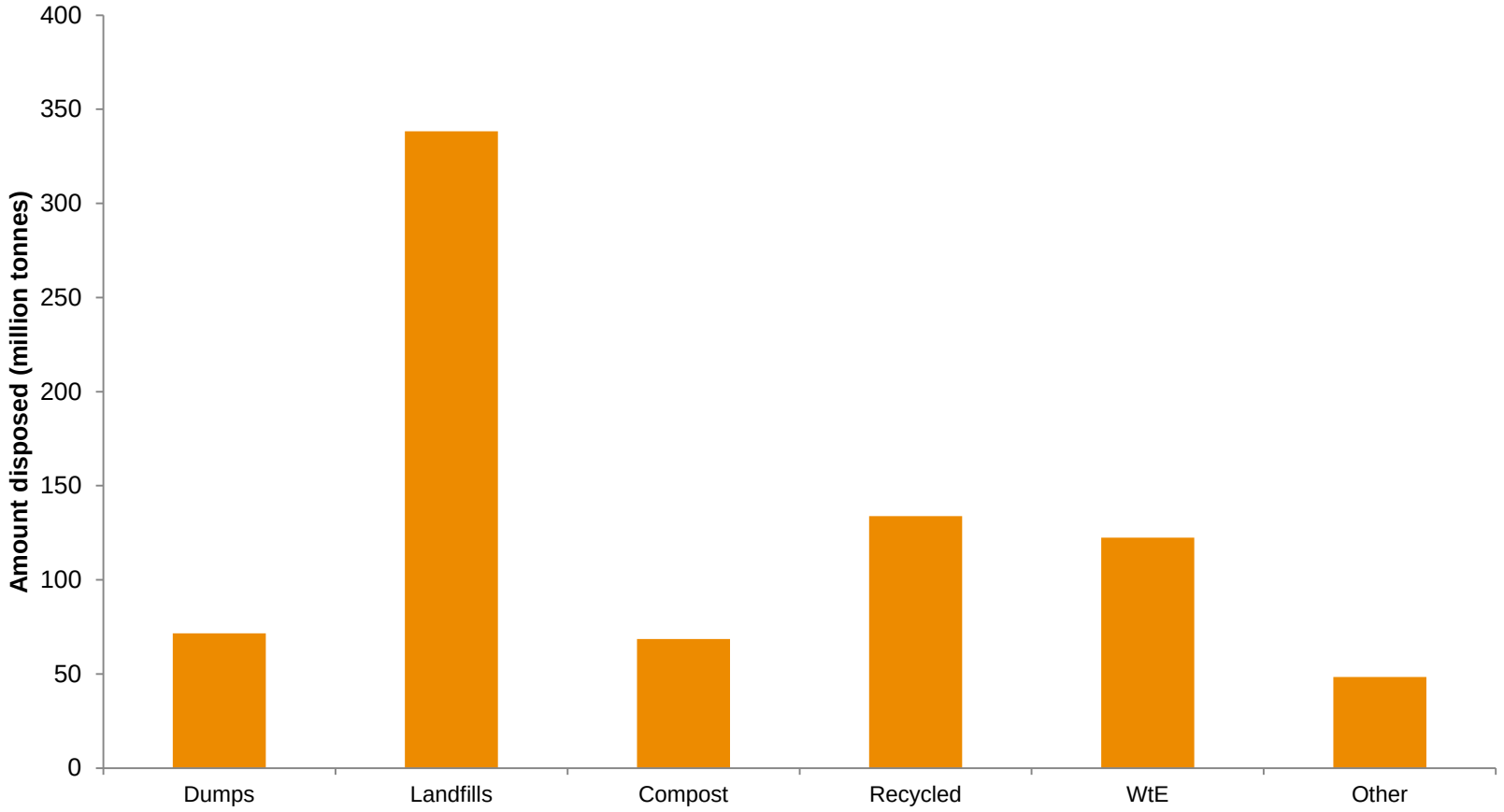
- The global WtE market was valued at US$25.32 billion in 2013, a growth of 5.5% on the previous year. WtE technologies based on thermal energy conversion lead the market, and accounted for 88.2% of total market revenue in 2013. The global market is expected to maintain its steady growth to 2023, when it is estimated it would be worth US$40 billion, growing at a CAGR of over 5.5% from 2016 to 2023.
- WtE remains a costly option for waste disposal and energy generation, in comparison with other established power generation sources and for waste management.
- Combustion plants are no longer a significant source of particulate emissions owing to the implementation of governmental regulations on emission control strategies, reducing the dioxin emissions by 99.9%.

Waste generation per capita (kg/day) to gross national income (GNI)



Source: Navigant Research, World Bank (2014)

Amount of waste disposed in 2012, by technique

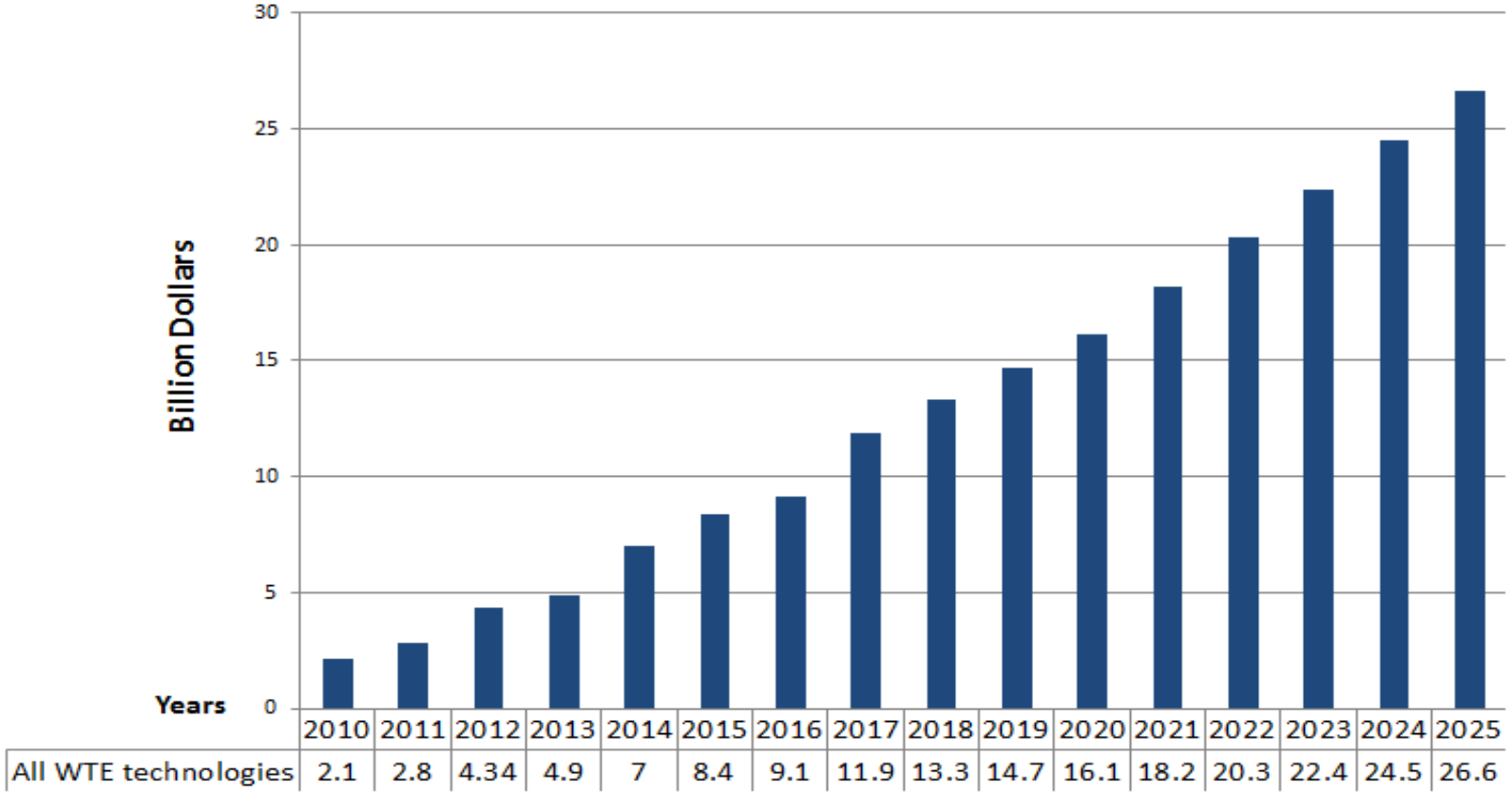


Source: Hoornweg & Bhada-Tata (2012)

Key findings

1. Europe is the largest and most sophisticated market for WtE technologies, accounting for 47.6% of total market revenue in 2013. The Asia-Pacific market is dominated by Japan, which uses up to 60% of its solid waste for incineration. However, the fastest market growth has been witnessed in China, which has more than doubled its WtE capacity in the period 2011-2015.
2. Biological WtE technologies will experience faster growth at an average of 9.7% per annum, as new technologies (e.g. anaerobic digestion) become commercially viable and penetrate the market.
3. From a regional perspective, the Asia-Pacific region will register the fastest growth (CAGR of 7.5%), driven by increasing waste generation and government initiatives in China and India and higher technology penetration in Japan.
4. It is estimated that global waste generation will double by 2025 to over 6 million tonnes of waste per day and the rates are not expected to peak before the end of this century. While OECD countries will reach ‘peak waste’ by 2050, and East Asia and Pacific countries by 2075, waste will continue to grow in Sub-Saharan Africa. By 2100, global waste generation may hit 11 million tonnes per day.

Growth of all WtE technologies globally with a conservative forecast up to 2025



Years	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
All WTE technologies	2.1	2.8	4.34	4.9	7	8.4	9.1	11.9	13.3	14.7	16.1	18.2	20.3	22.4	24.5	26.6

Source: Ouda & Raza (2014)

Solar energy

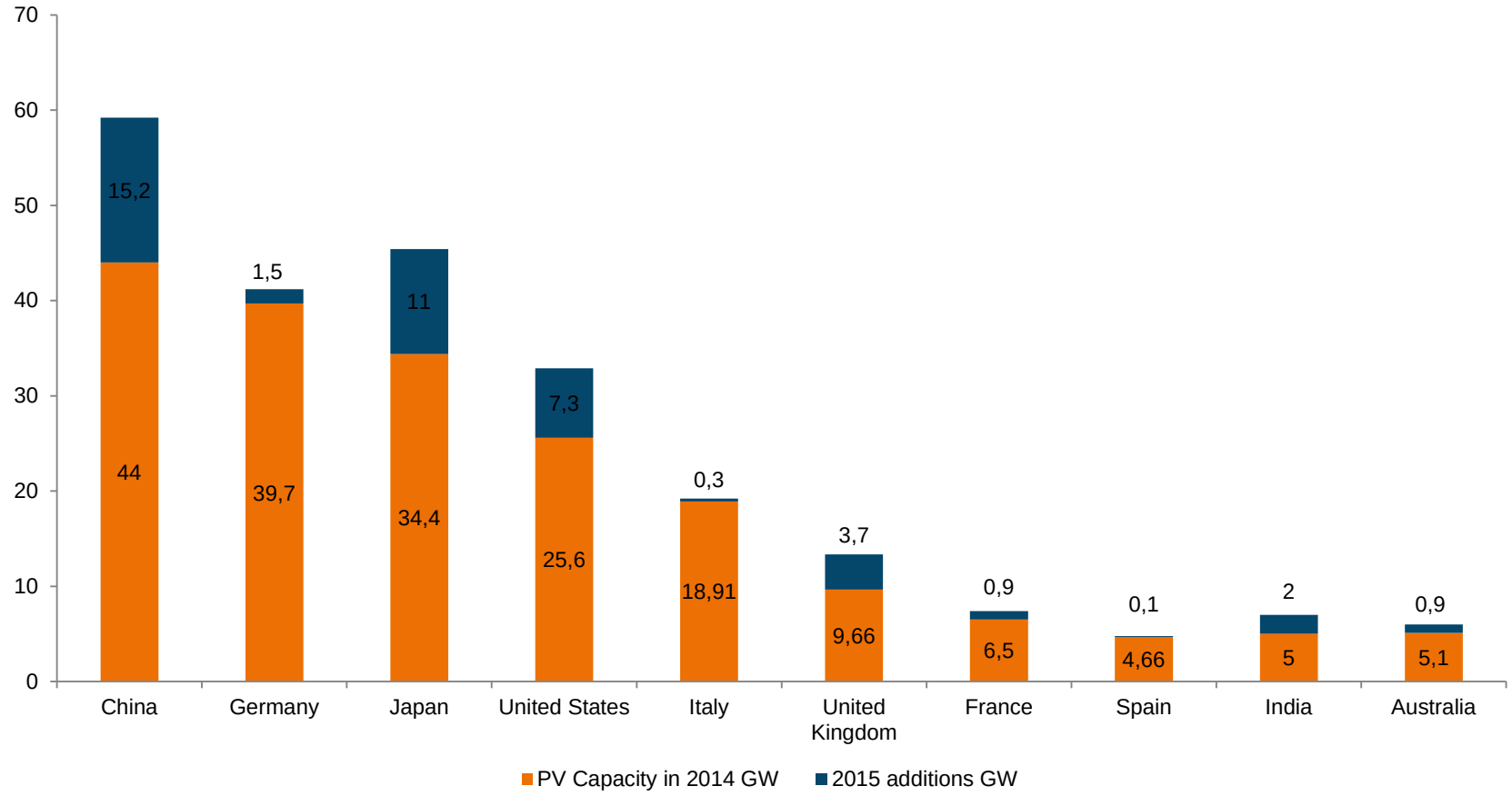
- Global installed capacity for solar-powered electricity has seen an exponential growth, reaching around 227 GWe at the end of 2015. It produced 1% of all electricity used globally.
- Major solar installation has been in regions with relatively less solar resources (Europe and China), while potential in high resource regions (Africa and Middle East), remains untapped. Germany has led PV capacity installations over the last decade and continues as a leader, followed by China, Japan, Italy and the United States.
- Expansion of solar capacity could be hindered by existing electricity infrastructure, particularly in countries with young solar markets. Solar PV and other renewable technologies are highly dependent on rare earth elements, which, besides general unstainable mining practices, also carry a high risk of some supply disruption.

Constraints and risks to materials consumed by solar PV

Element	R/P ratio (years)	Production constraint	Level of risk to solar industry
Cadmium	30	Environmental	High
Chromium	>16	Geopolitical & commercial	High
Gallium	N/A	Commercial	High
Germanium	N/A	Commercial	High
Indium	N/A	Commercial	Medium
Tellurium	N/A	Commercial	High

Source: BP Zepf (2014)

Top Solar PV capacity in 2014 and additions in 2015

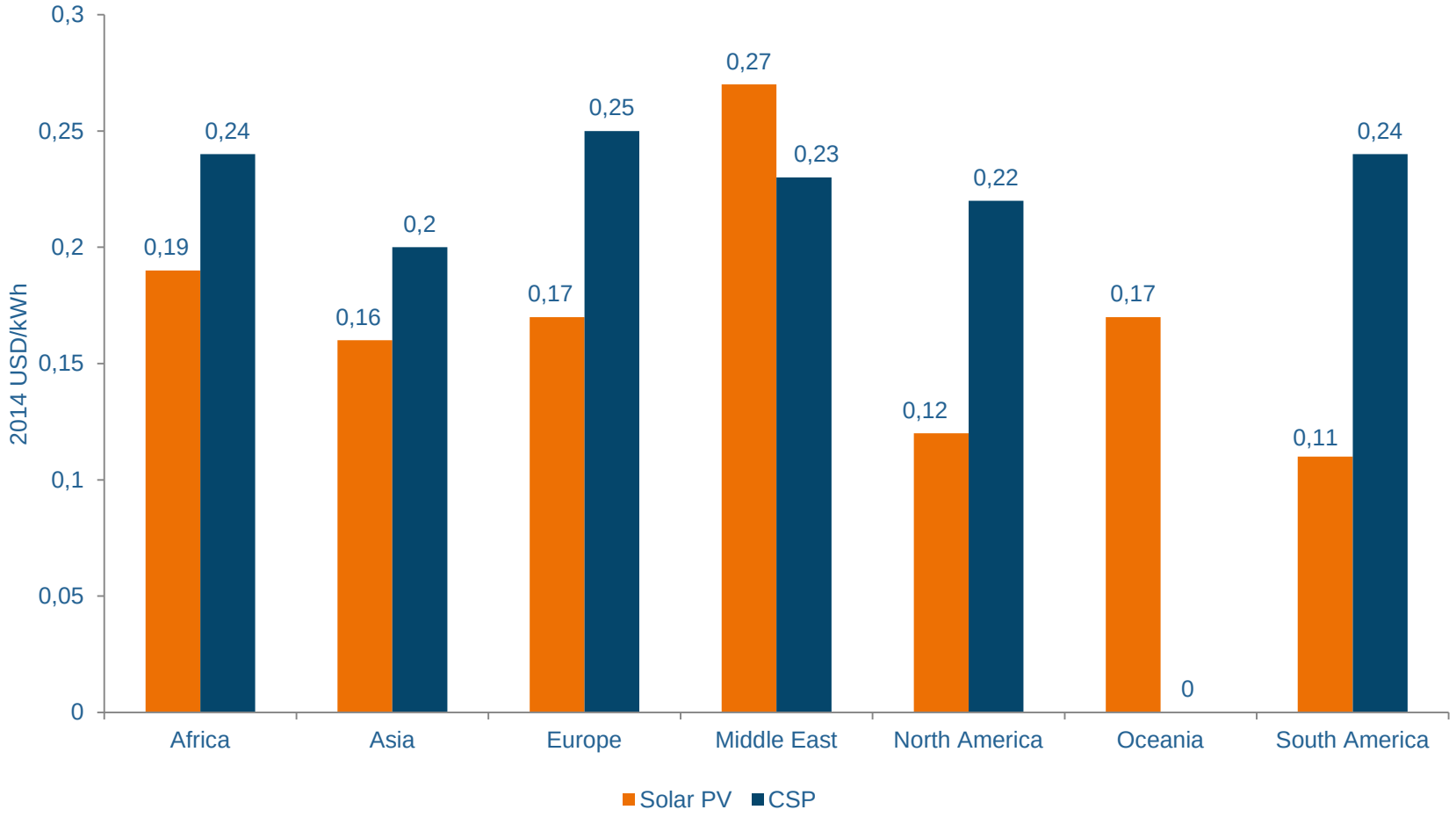


Source: REN21 (2016)

Key findings

1. Costs for solar power are falling rapidly and “grid parity” has been achieved in many countries, while new markets for the solar industry are opening in emerging and developing countries. Policy and regulatory incentives, oversupply of installation components, and advancements in technology are driving the reduction in cost.
2. Technology is constantly improving, and new technologies such as Perovskite cells are approaching commercialisation. While there has been continuous improvement in the conversion efficiency of PV cells, concentrated photovoltaics (CPV) may hold the key in enabling rapid increases in solar energy efficiency, recently reaching 46% for solar cells.
3. In order to prevent environmental damage from solar PV, there is a need for strict and consistent regulation on processes over the entire life-cycle of infrastructure. Disposal and recycling must be considered as more modules reach the end of their lifespan.

Average levelised cost of electricity for solar PV and CSP in 2014

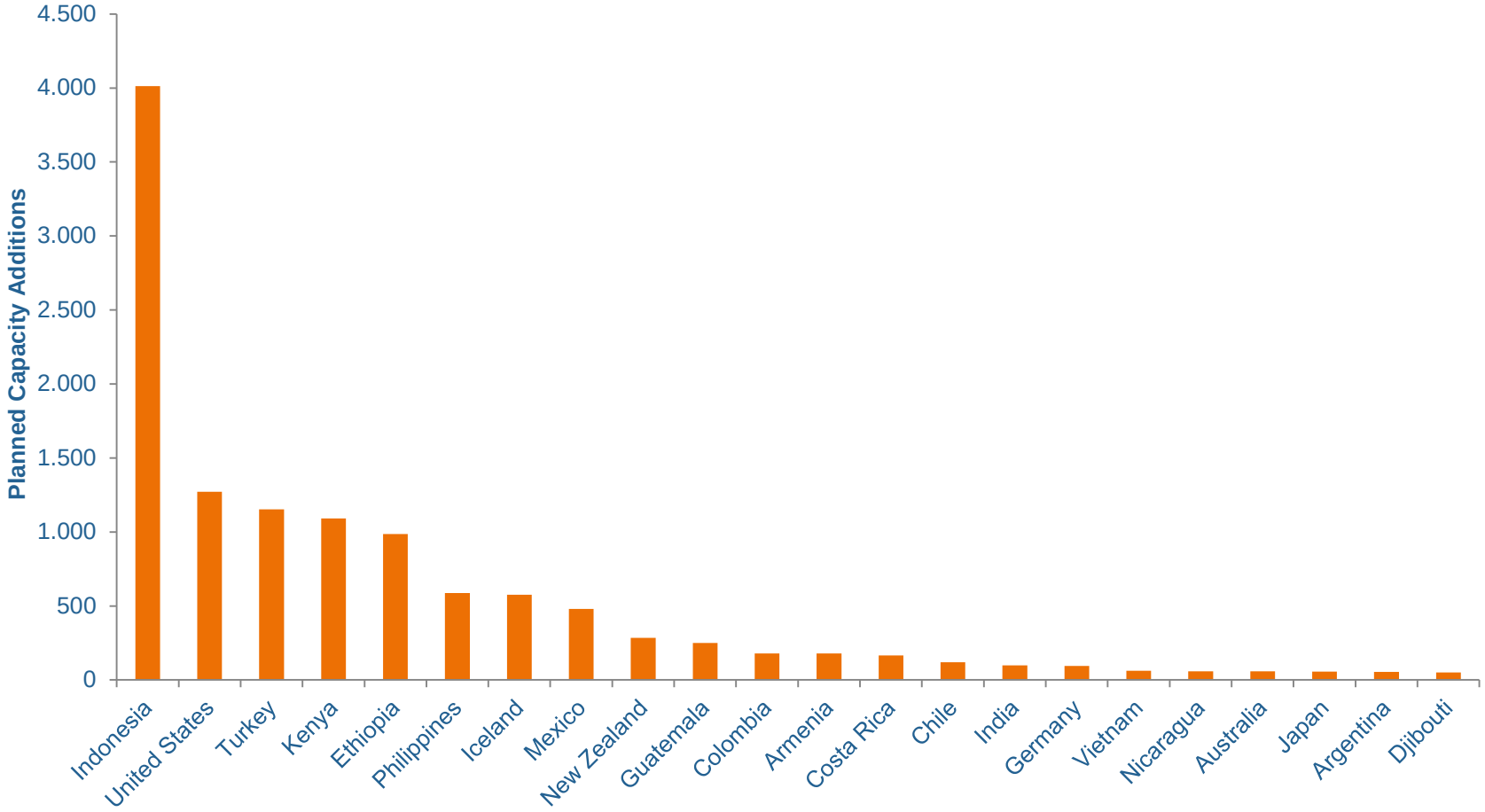


Source: IRENA (2016)

Geothermal energy

- Geothermal energy contributes a small proportion of the world's primary energy consumption. Electricity generation, geothermal produces less than 1% of the world's output. There were 315 MW of new geothermal power capacity installed in 2015, raising the total capacity to 13.2 GW.
- Turkey accounted for half of the new global capacity additions, followed by the US, Mexico, Kenya, Japan and Germany. In terms of direct use of geothermal heat, the countries with the largest utilisation, accounting for roughly 70% of direct geothermal in 2015, are China, Turkey, Iceland, Japan, Hungary, the US and New Zealand.
- The estimated stored thermal energy down to 3 km within continental crust, is roughly 43 x106 EJ, which is considerably greater than the world's total primary energy consumption. Geographically, 72% of installed generation capacity resides along tectonic plate boundaries or hot spot features of the Pacific Rim. A disproportional percentage of installed generation capacity resides on island nations or regions (43%), providing not only a valuable source of power generation, but also both heat and heat storage over a wide spectrum of conditions.

Capacity under development by country (MW)

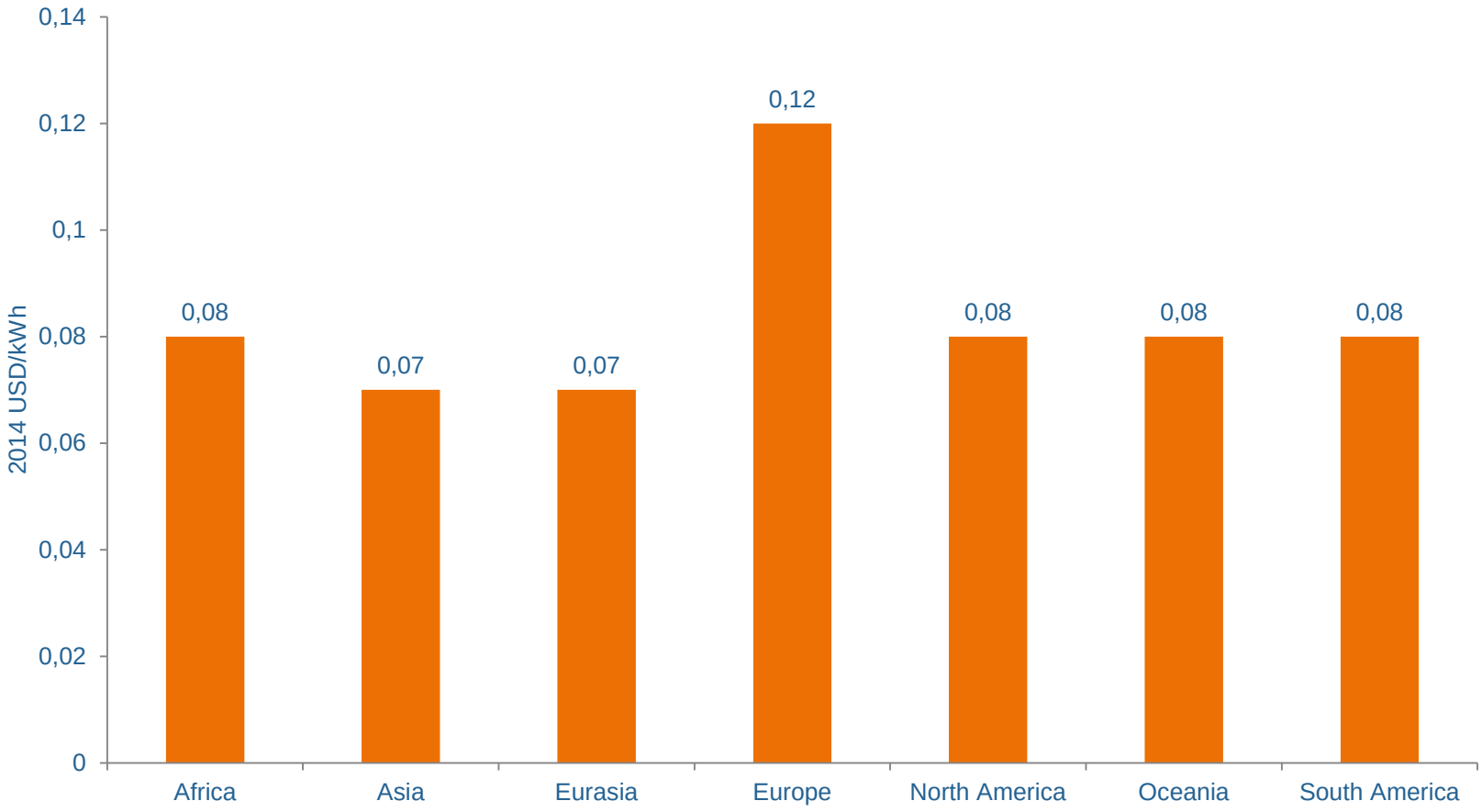


Source: GEA (2016)

Key findings

1. In 2015, total power output totalled 75 TWh, the same number being also valid for total heat output from geothermal energy (excluding ground heat pumps). World geothermal heat use (direct & storage) reached 563 PJs in 2014.
2. Global investment in 2015 was US$2 billion, a 23% setback from 2014. During the period 2010-2014, around US$20 billion were invested in geothermal energy by 49 countries for both direct use and electric power.
3. Geothermal energy currently finds itself burdened by higher installation costs and longer development periods, relative to solar and wind. As a result, in many countries, geothermal energy projects have been and are reliant on government incentives in order to compete against both natural gas and other renewable generation.
4. The pace of geothermal development has been conditioned by legal frameworks and particularly by conservation legislation. However, the pace of development might accelerate due to climate change concerns and the increasing need to decarbonise the energy sector.

Average levelised cost of electricity for geothermal in 2014, by region

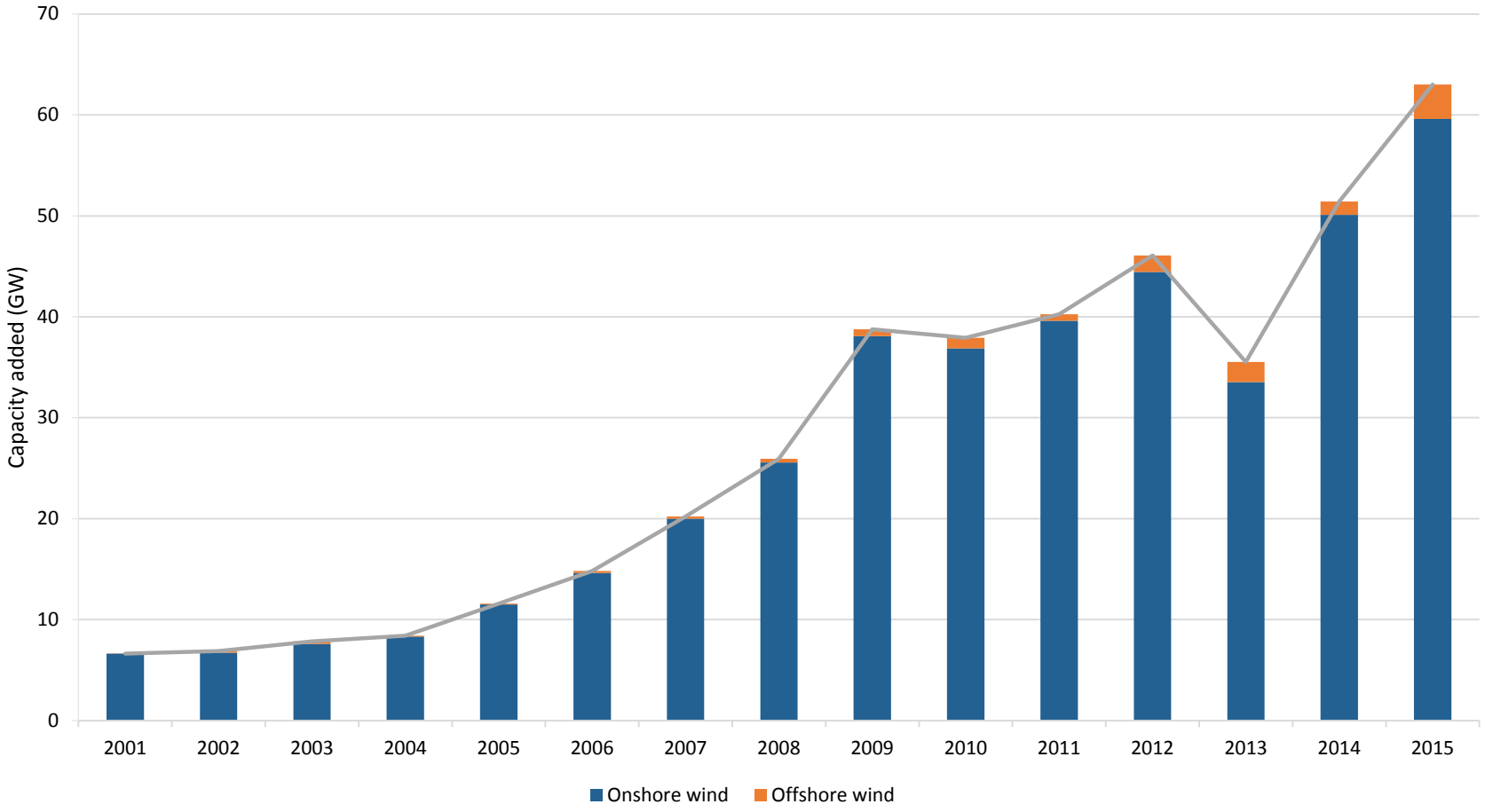


Source: IRENA (2016)

Wind energy

- World wind power generation capacity has reached 435 GW at the end of 2015, around 7% of total global power generation capacity. A record of 64 GW was added in 2015. The global growth rate of 17.2% was higher than in 2014 (16.4%).
- Global wind power generation amounted to 950 TWh in 2015, nearly 4% of total global power generation. Denmark produced 42% of its electricity from wind turbines in 2015, the highest figure yet recorded worldwide. In Germany wind power contributed a new record of 13% of the country's power consumption in 2015.
- The next generation of advanced large offshore wind turbines, reduced costs for foundations and more efficient project development practices could reduce the LCOE of offshore wind from US$19.6 cents per kWh in 2015 to roughly 12 cents per kWh in 2030. Global installed capacity of offshore wind capacity reached around 12 107 MW end-2015, with 2 739 turbines across 73 offshore wind farms in 15 countries. Currently, more than 92% (10 936 MW) of all offshore wind installations are in European waters. Floating foundations technologies are in development and several full-scale prototype floating wind turbines have been deployed.

Annual net global wind capacity additions, 2001-2015

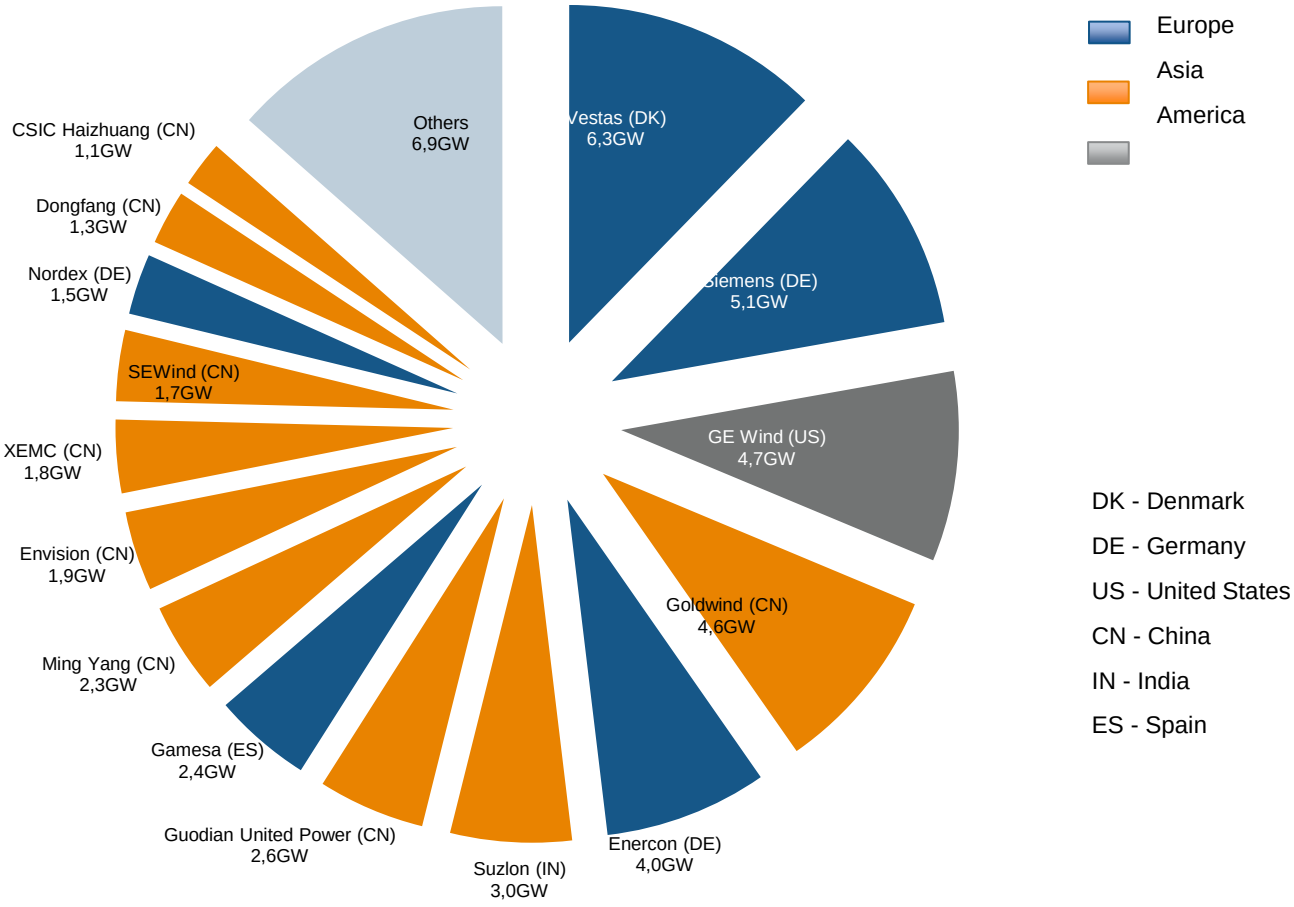


Source: IRENA, GWEC

Key findings

1. With current policy plans, global wind capacity could grow from 435 GW in 2015 to 977 GW in 2030 (905 GW onshore and 72 GW offshore wind). The global leaders in wind power as at end-2015 are China, the US, Germany, India and Spain.
2. The total investments in the global wind sector reached a record level of US$109.6 billion over the course of 2015.
3. For onshore wind, China has the lowest weighted average LCOE with a range between US$50/MW – US$72/MW, while the highest weighted average LCOE are found in Africa, Oceania and Middle East with US$95/MW, US$97/MW and US$99/MW.
4. Wind deployment continues to be dominated by onshore wind, supported by continual cost reductions. LCOE for offshore wind has continued to decrease owing to a wide range of innovations. Floating foundations could be game changers in opening up significant new markets with deeper waters.
5. Trends within the supplier industry in recent years show strong consolidation of the major companies and the shift in the global wind market eastwards to China and India.

Share of the global turbine manufacturer market, with respective capacity additions, in 2014gs



Source: BTM Navigant (2015)

Marine energy

- To date only a handful of commercial ocean energy projects have been delivered, reflecting the current immaturity and high costs of these technologies, as well as the challenging market environment in which they operate.
- 0.5 GW of commercial ocean energy generation capacity is in operation and another 1.7 GW under construction, with 99% of this accounted for by tidal range. Relatively few commercial scale wave, tidal stream or OTEC projects are operational. Three tidal stream commercial projects accounting for 17 MW of capacity are to be commissioned shortly, (two in Scotland and one in France), and a 1 MW commercial wave energy array in Sweden.
- Sweden has begun construction of the world's largest commercial wave energy array at Sotenas. It will incorporate 42 devices and deliver 1.05 MW of capacity. They have also recently installed a second project in Ghana consisting of 6 devices, together providing 400 kW of capacity.

Regional theoretical potential of wave energy

REGION	Wave Energy TWh/yr
Western and Northern Europe	2 800
Mediterranean Sea and Atlantic Archipelagos (Azores, Cape Verde, Canaries)	1 300
North America and Greenland	4 000
Central America	1 500
South America	4 600
Africa	3 500
Asia	6 200
Australia, New Zealand and Pacific Islands	5 600
TOTAL	**29 500**

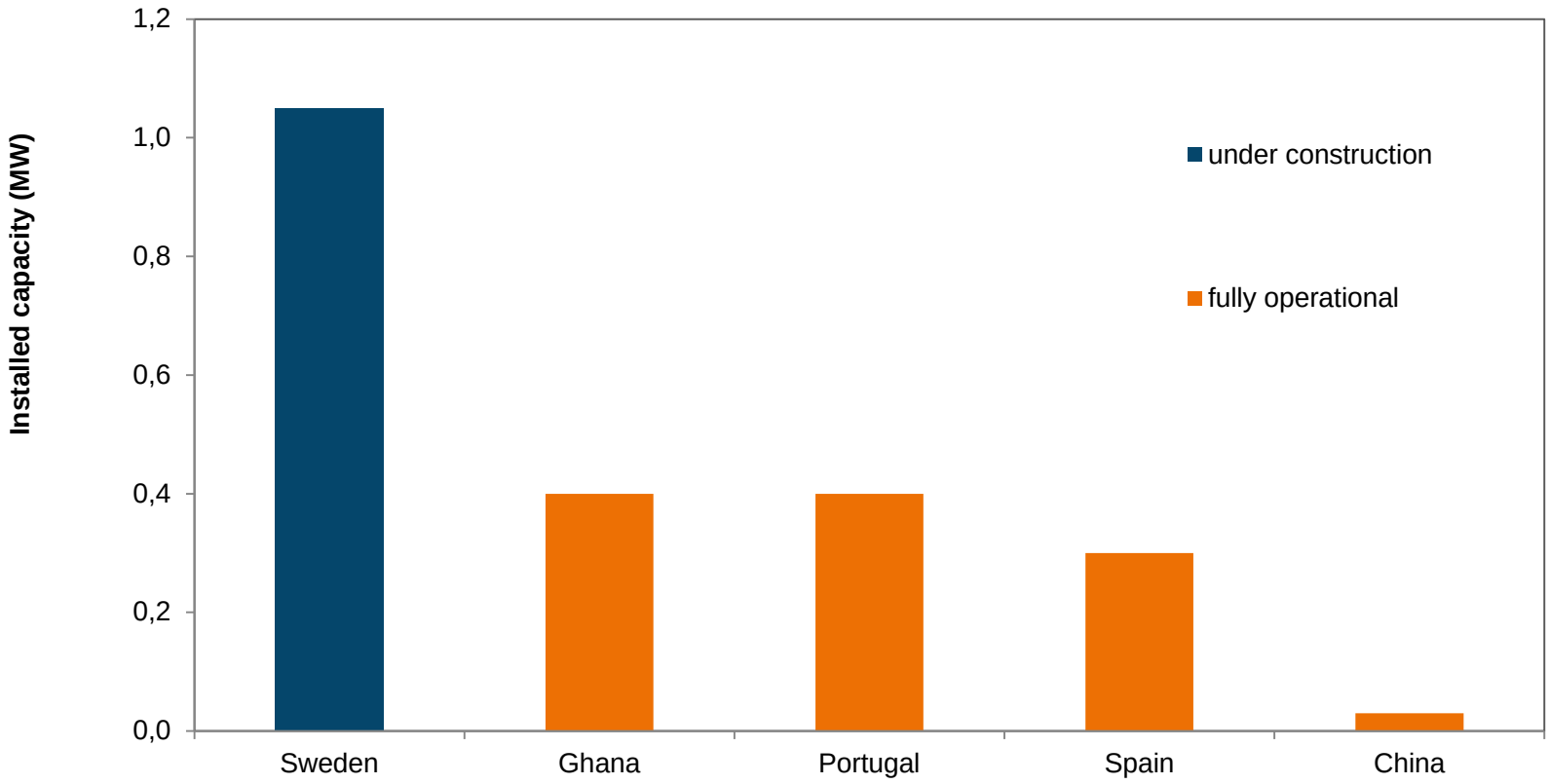
Source: (Mørk et al. 2010)

Note: The total resource potential is less than 32,000 TWh/yr quoted previously as the table accounts for only theoretical wave power P≥ 5 kW/m and latitude ≤66.5º

Key findings

1. 2015 estimates the LCOE of wave energy at approximately US$500/MWh whilst tidal sits at approximately US$440/MWh. The LCOE for small-scale OTEC plants (1-10 MW) ranges somewhere between US$190/MWh and US$940/MWh, however if the facility were to be scale up to between 50-400 MW the cost would fall dramatically to a range between US$70/MWh and U$320/MWh.
2. The high costs illustrate the immaturity of these technologies and the relatively short gestation period that ocean energy technologies, with the exception of tidal range, have undergone. Despite positive developments, a large number of projects have been suspended as public and private funds have been withdrawn, but many of the cost issues could be addressed through ongoing RD&D efforts.
3. There is 15 GW of ocean energy projects at various stages of the development pipeline with, the majority of these are tidal range (11.5 GW) followed by tidal stream (2.6 GW), wave (0.8 GW) and OTEC (0.04 GW).

Wave energy installed capacity in operation or under construction



Source: (OES 2016a)

Carbon capture and Storage (CCS)

- The world's first large-scale application of CO2 capture technology in the power sector commenced operation in October 2014 at the Boundary Dam power station in Saskatchewan, Canada. In the US, two additional demonstrations of large-scale CO2 capture in the power sector, at the Kemper County Energy Facility in Mississippi and the Petra Nova Carbon Capture Project in Texas are planned to come into operation in 2016-2017.
- CCS is currently the only available technology that can significantly reduce GHG emissions from certain industrial processes and it is a key technology option to decarbonise the power sector, especially in countries with a high share of fossil fuels in electricity production.
- In terms of the scale of CCS deployment, there are 22 large-scale CCS projects currently in operation or under construction around the world, with the capacity to capture up to 40 million tonnes of CO2 per year (Mtpa). These projects cover a range of industries, including gas processing, power, fertiliser, steel-making, hydrogen-production (refining applications) and chemicals. They are located predominantly in North America, where the majority of CO2 capture capacity is intended for use in EOR.

Selected key estimates of effective storage resources

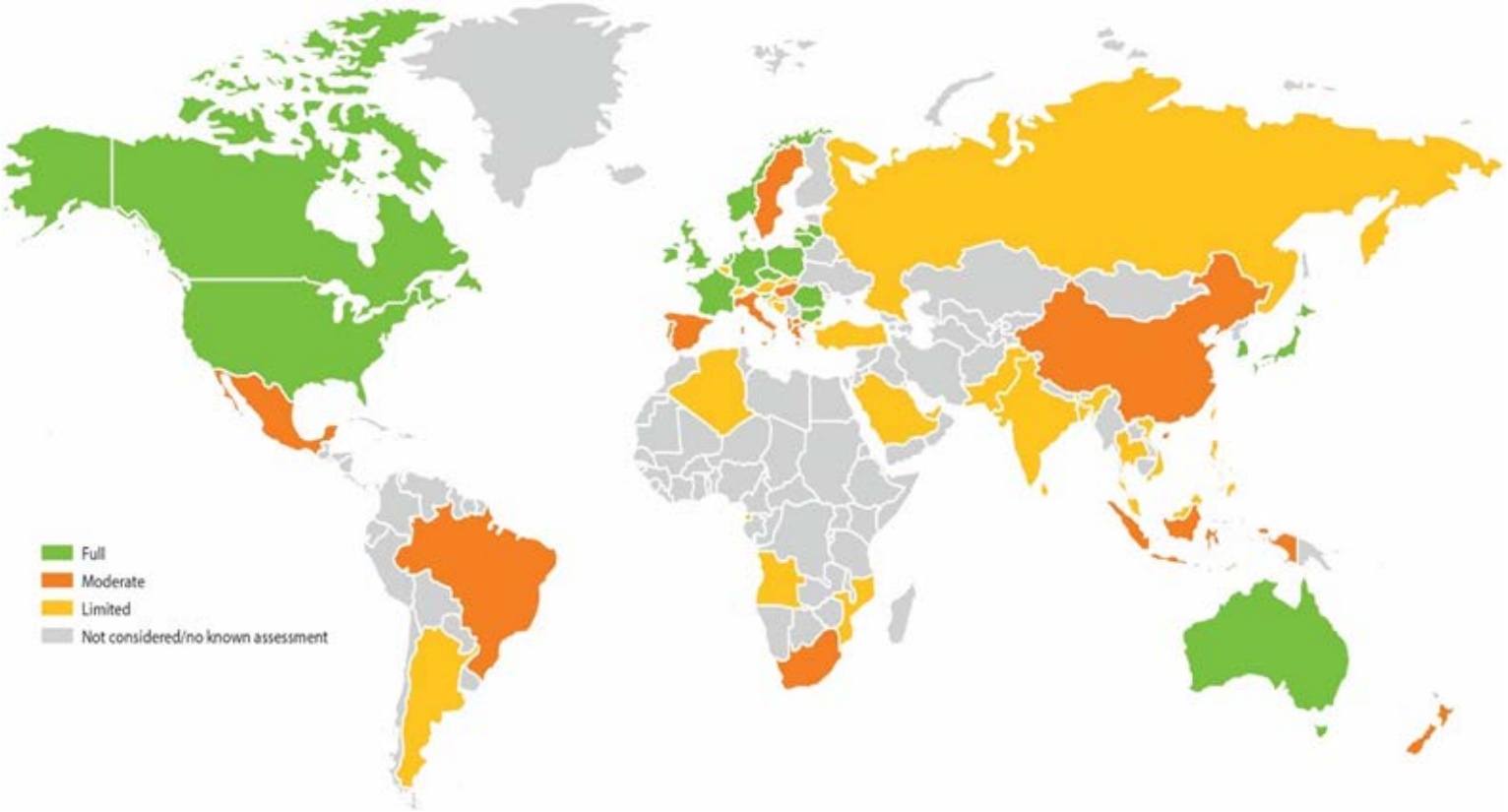
Country	Estimated storage resource (Gigatonnes)	
	Deep saline formations	EOR/depleted fields
USA	2,379 to 21,633	186 to 232
Europe	96	20
China	3,000*	2.2
Australia	33 to 230	17

Note: the example resource estimates above have been calculated based on geological characteristics and do not account for economic or regulatory factors.
*Resources only calculated at theoretical level

Key findings

1. Even though the cost of CO2 transportation is relatively low compared to the cost associated with capturing and storing the CO2, the scale of investment in CO2 transportation infrastructure required to support large-scale deployment of CCS will be considerable.
2. Total global CO2 capture capacity of projects in operation or under construction is around 40 Mtpa. The large-scale projects in operation around the world demonstrate the viability of CCS technology.
3. The Japanese Government is collaborating with technology providers in industry to examine suitable storage sites and the economic feasibility of CCS deployment.
4. The South Korean Government CCS Master Plan includes a large-scale CCS demonstration project operating within certain cost parameters by 2020, and commercial CCS deployment thereafter.
5. In Australia, considerable project activity continues. The Gorgon Carbon Dioxide Injection Project is expected to be operational in 2017. It will be Australia's first large-scale CO2 injection project and the largest in the world injecting CO2 into a deep saline formation.
6. The Middle East has two large-scale CCS projects. Main project efforts are centred in Saudi Arabia and Abu Dhabi, although Qatar is also examining CCS opportunities.

Status of national assessments of regional storage resources

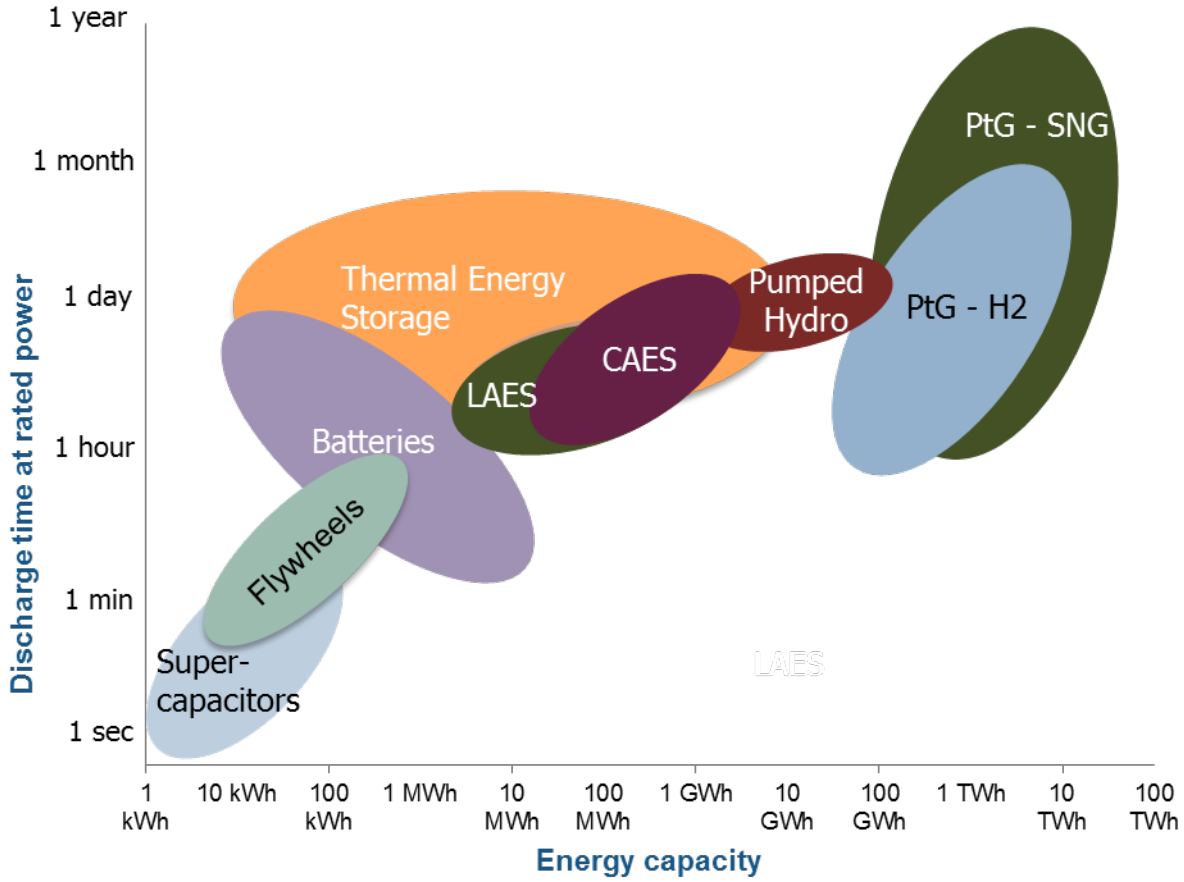


Source: Global CCS Institute, 2015: *The Global Status of CCS 2015*

E-storage

- Energy storage development has been mainly restricted to one technology until recently. Pumped hydro storage accounts for well over 95% of global installed energy storage capacity. Compressed air energy storage currently has only two commercial plants (in Germany and the US), in total 400 MW, with a third under development in the UK.
- Battery storage capacity is increasing: for example, there are around 25 000 domestic installations in Germany alone in conjunction with solar PV installations, with total capacity of 160 MWh. The total battery capacity in electric vehicles is also growing rapidly. Millions of water heaters have been operated in France for decades and these small-scale energy storage installations are not necessarily well represented in global statistics.
- Large batteries are also being developed with installed capacity amounting to almost 750 MW worldwide. Sodium-sulphur became the dominant technology in the 2000s, accounting for nearly 60% of stationary battery projects (441 MW). In recent years, lithium-ion technology has become more popular. Flow batteries, if developed further, could be a game changer in the medium term.

Mapping storage technologies according to performance characteristics

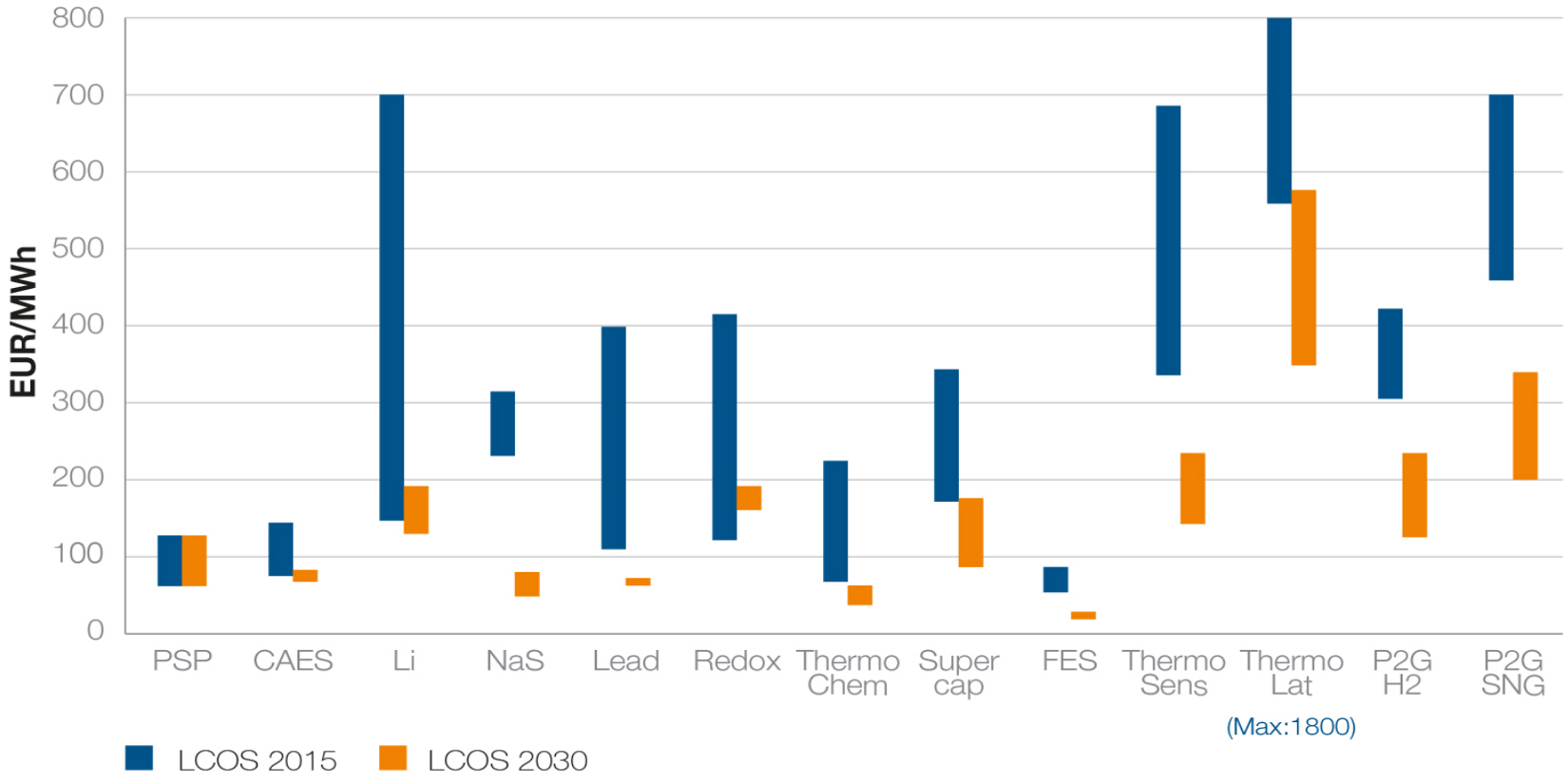


Source: PwC (2015) following Sterner et al. (2014)
CAES: Compressed Air, LAES: Liquid Air, PtG: Power to Gas

Key findings

- The main areas of growth in the next five years are likely to be:
  - Small-scale battery storage in conjunction with solar PV. There are already around 25 000 residential-scale units in Germany alone, and this could grow to 150 000 by 2020.
  - Utility-scale electricity storage, for multiple purposes, especially frequency response.
  - Electric vehicles.
  - Commercial, communications and software capabilities to allow multiple small distributed storage, demand response and distributed generation sources to be aggregated, in a ‘virtual power plant’ or ‘swarm’.
  - Pumped storage hydro, especially in south-east Asia, Africa and Latin America.
  - Isolated electricity systems such as islands, to aid integration of renewables in order to save fuel costs.
- Most commercial interest is in battery storage and the costs of several storage technologies will fall as production volumes increase.
- The future outlook for energy storage markets is good due to an increasing need, but the regulatory and legal frameworks are failing to keep pace.

Levelised cost of storage in 2015 study period and 2030 (€ 2014)



Source: PwC (2015)

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Thank you

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