HELE coal-fired power generation roadmap milestones

		2010	2020		2030 – 2040 – 2050
PC combustion	Hard coal	Deploy more supercritical and USC plants. Continue R&D on A-USC.	Deploy more USC plants. Demonstrate A-USC. Test A-USC with post-combustion CO_2 capture at pilot scale. Test oxy-fuel A-USC at pilot scale.	Deploy A-USC. Demonstrate oxy-fuel A-USC.	Deploy A-USC with integrated CCS. Deploy oxy-fuel A-USC.
PC combustion	Brown coal	Deploy more SC and demonstrate USC plants. Demonstrate lignite drying on full-scale power plant.	Deploy lignite drying on full-scale power plant. Deploy USC plants. Demonstrate A-USC with partial CO_2 capture.	Deploy USC with 100% fuel drying. Demonstrate A-USC with full-flow dry feed boiler. Demonstrate A-USC with full-flow CO_2 capture.	Deploy A-USC incorporating drying with full CCS.
IGCC		Deploy units with 1 400°C to 1 500°C gas turbines. Improve availability and performance with low-grade coals. Test at pilot scale dry gas cleaning and non-cryogenic provision of oxygen. Develop gas turbines with turbine inlet temperatures over 1 500°C.	Deploy units with 1 600°C gas turbines for high hydrogen fuel for CCS capability. Support R&D for dry syngas cleaning. Some non-cryogenic oxygen application.	Deploy units with 1 700°C gas turbines for high hydrogen fuel for CCS capability. Further application of non-cryogenic oxygen.	Deploy units with 1 700°C+ gas turbines for high hydrogen fuel with full CCS. Deploy non-cryogenic oxygen option.
CFBC		Deploy supercritical and demonstrate USC CFBC boilers.	Deploy USC CFBC.	Demonstrate A-USC CFBC. Test A-USC oxy-fuel at pilot scale. Initial deployment of A-USC.	Deploy A-USC CFBC with full CCS; both post-combustion capture and oxy-fuel.
Non-GHG emissions	SO_2	PC = <20 mg/m^3; limestone/gypsum FGD IGCC = <20 mg/m^3 for wet scrubbing; dry methods are under development CFBC = <50 mg/m^3		<10 mg/m^3 for PC, IGCC and CFBC.	
Non-GHG emissions	NO_x	PC = 50 to 100 mg/m^3; combustion measures (*i.e.* low-NO_x burners and air staging) plus SCR IGCC = <30 mg/m^3; SCR will allow lower levels CFBC = <200 mg/m^3		<10 mg/m^3 for PC, IGCC and CFBC.	
Non-GHG emissions	PM	PC = <5-10 mg/m^3, even with ESPs, IGCC = <1 mg/m^3, CFBC = <50 mg/m^3, with ESP and fabric filters		<1 mg/m^3 for PC and CFBC / 0.1 mg/m^3 for IGCC.	

PM = particulate matter
FGD = flue gas desulphurisation
SCR = selective catalytic reduction
ESP = electrostatic precipitator

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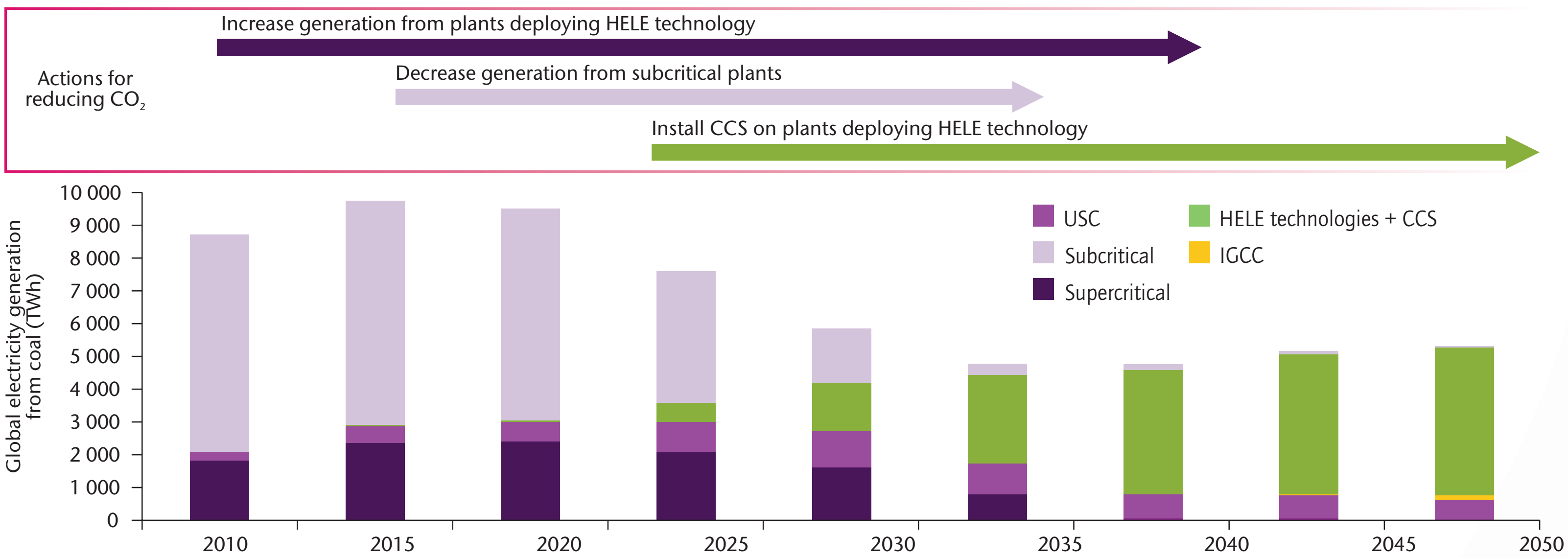
HELE COAL-FIRED POWER GENERATION ROADMAP

International Energy Agency

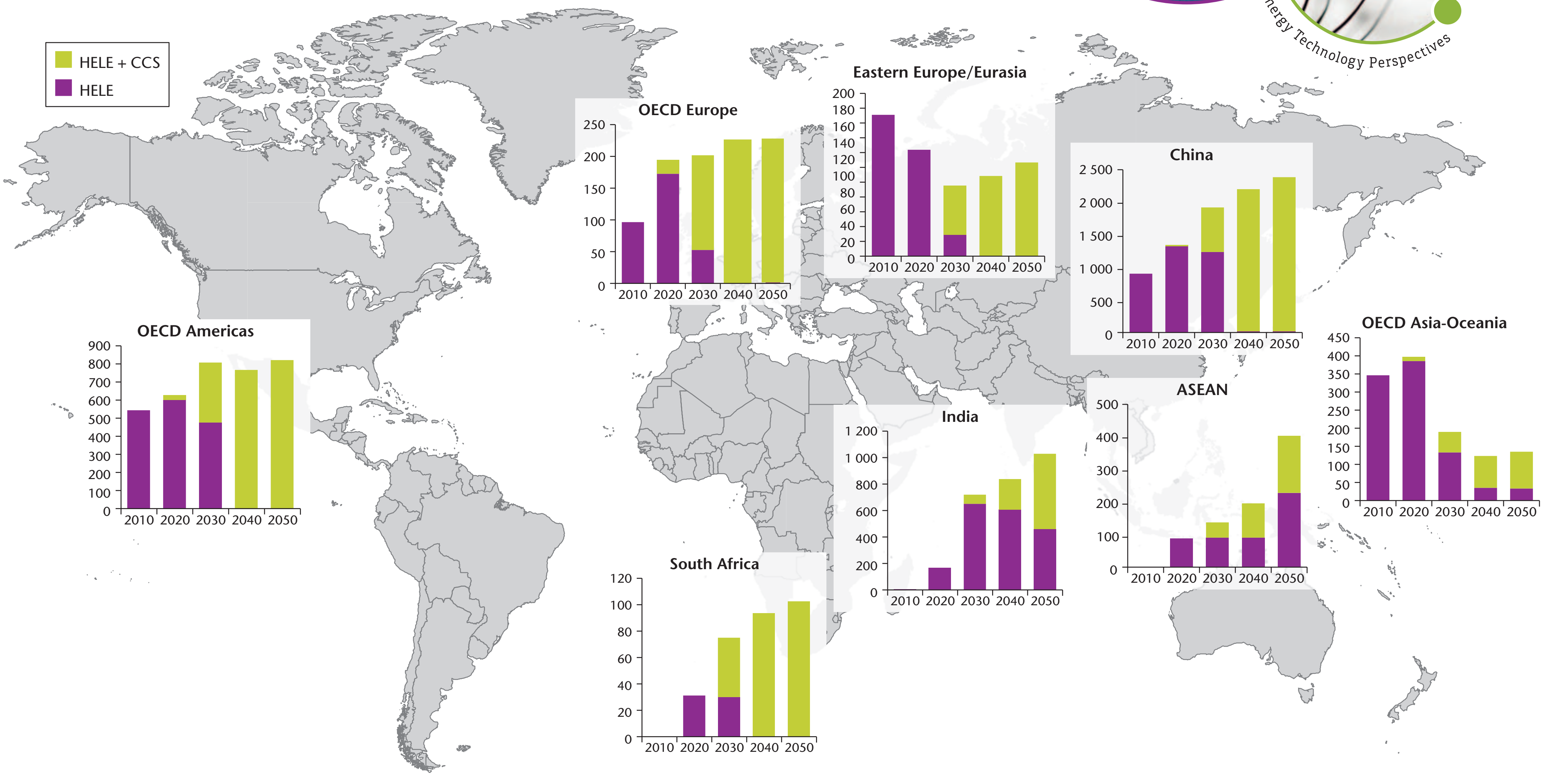
Projected electricity generation from coal-fired power generation technologies in IEA ETP 2°C Scenario



Key findings

- In 2011, roughly 50% of new coal-fired power plants used high-efficiency, low-emissions (HELE) technologies, predominantly supercritical (SC) and ultra-supercritical (USC) pulverised coal combustion units. Though the share of HELE technology has almost doubled in the last 10 years, far too many non-HELE, subcritical units are still being constructed. About three-quarters of operating units use non-HELE technology; more than half of current capacity is over 25 years old and comprises units of less than 300 MW.
- USC pulverised coal combustion is currently the most efficient HELE technology: some units reach efficiency of 45% (LHV, net), reducing global average emissions to 740 grams of carbon dioxide per kilowatt hour (gCO_2/kWh). Efforts to develop advanced USC technology could lower emissions to 670 gCO_2/kWh (a 30% improvement). Deployment of advanced USC is expected within the next 10 to 15 years.
- To raise its efficiency, integrated gasification combined cycle (IGCC) needs to operate with gas turbines that allow higher turbine inlet temperatures. IGCC with 1 500°C-class gas turbines (currently under development) should be able to raise efficiency well above 45%, bringing CO_2 emissions down towards 670 gCO_2/kWh – and less for IGCC units with more advanced gas turbines.
- To achieve CO_2 intensity factors that are consistent with halving CO_2 emissions by 2050, deployment of carbon capture and storage (CCS) is essential. CCS offers the potential to reduce CO_2 emissions to less than 100 g/kWh. Programmes to demonstrate large-scale, integrated CCS on coal-fired power units are under way in many countries. Some deployment of CCS is anticipated in the 2020s, with broader deployment projected from 2030-35 onwards.
- HELE technologies need to be further developed as:
  - inefficient power generation from low-cost, poor quality coal is currently being used by many countries;
  - though trials have demonstrated the potential to reduce emissions by co-firing biomass, the practice is not widespread; and
  - operating coal-fired power plants consume copious quantities of water, a cause of major concern in arid regions and regions where water resources issues are gaining prominence.
- Non-greenhouse gas pollutants can cause severe health issues and often harm local infrastructure and, consequently, the local economy. Though technologies are available for reducing their emissions, not all countries yet deploy them effectively. can cause severe health issues and often harm local infrastructure and, consequently, the local economy.

Electricity generation (TWh) from HELE coal-fired power generation in IEA ETP 2°C Scenario



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Key actions over the next 10 years

- Increase – by about 4 percentage points – the average efficiency of coal-fired power generation plants. This implies substantially reducing generation from older, inefficient plants, improving the performance of operational plants, and installing new, highly efficient, state-of-the-art plants.
- Deploy, at minimum, supercritical technology on all new combustion installations producing over 300 MWe and avoid installation of smaller sized units (on which it is impractical to apply supercritical conditions) where possible.
- Provide funding and support mechanisms for research, development, demonstration and deployment (RDD&D) to enable the timely deployment of next-generation technologies, in particular to:
  - demonstrate advanced combustion and gasification technologies;
  - demonstrate the integration of CO_2 capture with state-of-the-art combustion and gasification technologies;
  - improve the efficiency of generation from indigenous, low-cost, low-quality coal; and
  - reduce the water consumption of HELE technologies, while maintaining their performance.
- Develop and deploy – possibly through mandatory policies – efficient and cost-effective flue-gas treatment to limit non-GHG emissions. Initiate or improve pollutant monitoring, promoting joint responsibility on the part of the users and the appropriate authority to verify full compliance with legislation and to ensure the technology applied is meeting its potential.

Regional outlook from HELE coal-fired power generation

ASEAN	6°C Scenario				2°C Scenario			
	2015	2020	2030	2050	2015	2020	2030	2050
HELE capacity w/o CCS (GW)	1	1	9	99	7	13	13	33
HELE capacity with CCS (GW)	0	0	0	0	0	0	7	25
Share of HELE capacity	1%	1%	7%	42%	13%	21%	30%	64%

China	6°C Scenario				2°C Scenario			
	2015	2020	2030	2050	2015	2020	2030	2050
HELE capacity w/o CCS (GW)	237	254	483	1 209	232	243	226	39
HELE capacity with CCS (GW)	0	0	0	0	0	2	97	344
Share of HELE capacity	29%	26%	38%	66%	32%	33%	45%	70%

Eastern Europe/Eurasia	6°C Scenario				2°C Scenario			
	2015	2020	2030	2050	2015	2020	2030	2050
HELE capacity w/o CCS (GW)	40	46	55	88	36	34	4	0
HELE capacity with CCS (GW)	0	0	0	0	0	0	11	20
Share of HELE capacity	35%	33%	25%	29%	38%	38%	38%	62%

India	6°C Scenario				2°C Scenario			
	2015	2020	2030	2050	2015	2020	2030	2050
HELE capacity w/o CCS (GW)	23	23	109	404	23	23	109	81
HELE capacity with CCS (GW)	0	0	0	0	0	0	10	81
Share of HELE capacity	13%	12%	39%	80%	14%	16%	50%	88%

OECD Asia Oceania	6°C Scenario				2°C Scenario			
	2015	2020	2030	2050	2015	2020	2030	2050
HELE capacity w/o CCS (GW)	60	66	81	127	58	60	27	6
HELE capacity with CCS (GW)	0	0	0	0	0	2	9	16
Share of HELE capacity	54%	56%	63%	90%	53%	56%	80%	99%

OECD Europe	6°C Scenario				2°C Scenario			
	2015	2020	2030	2050	2015	2020	2030	2050
HELE capacity w/o CCS (GW)	40	47	71	129	39	40	11	0
HELE capacity with CCS (GW)	0	1	4	8	1	4	26	40
Share of HELE capacity	20%	24%	41%	85%	20%	22%	35%	90%

United States	6°C Scenario				2°C Scenario			
	2015	2020	2030	2050	2015	2020	2030	2050
HELE capacity w/o CCS (GW)	97	97	184	340	97	97	78	0
HELE capacity with CCS (GW)	0	0	0	0	1	3	44	111
Share of HELE capacity	28%	27%	49%	81%	29%	31%	55%	100%

Other OECD North America	6°C Scenario				2°C Scenario			
	2015	2020	2030	2050	2015	2020	2030	2050
HELE capacity w/o CCS (GW)	2	2	7	24	2	2	1	0
HELE capacity with CCS (GW)	0	0	0	0	0	0	4	8
Share of HELE capacity	8%	8%	20%	60%	7%	9%	50%	100%

South Africa	6°C Scenario				2°C Scenario			
	2015	2020	2030	2050	2015	2020	2030	2050
HELE capacity w/o CCS (GW)	5	5	5	5	5	5	5	0
HELE capacity with CCS (GW)	0	0	0	0	0	0	6	15
Share of HELE capacity	11%	11%	10%	8%	11%	11%	27%	100%

World	6°C Scenario				2°C Scenario			
	2015	2020	2030	2050	2015	2020	2030	2050
HELE capacity w/o CCS (GW)	519	560	1 026	2 509	510	530	480	160
HELE capacity with CCS (GW)	0	1	4	8	3	12	215	664
Share of HELE capacity	27%	26%	39%	68%	28%	30%	46%	78%

Note: HELE capacity is a total of plants with the efficiencies over supercritical.
Share of HELE capacity corresponds to the ratio of HELE capacity in total coal-fired power plants.

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