University of Glasgow

A WORLD TOP 100 UNIVERSITY

Geothermal Energy and Opportunities for the Oil and Gas Industry

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Rankine Chair of Energy Engineering

WORLD CHANGING GLASGOW

THE TIMES THE SUNDAY TIMES GOOD UNIVERSITY GUIDE 2024

SCOTTISH UNIVERSITY OF THE YEAR

UofG is taking the lead to tackle climate change

- 2014: 1st EU university to commit to fully divesting from fossil fuel companies.
- 2017: Endorsed the UN's SDGs.
- 2019: 1st university in Scotland to declare a climate emergency.
- 2020: Published Glasgow Green, our strategy to tackle climate change.
- 2024: Completed divestment from fossil fuels.
- 2030: Our target date to achieve net-zero carbon emissions.

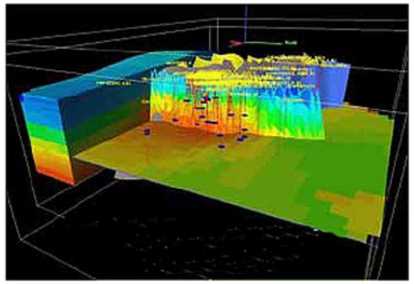
Summary

- Geothermal / oil&gas synergies
- Net-Zero challenge
- Tracking progress
- Shifting investment
- Selected priorities
- Conclusions

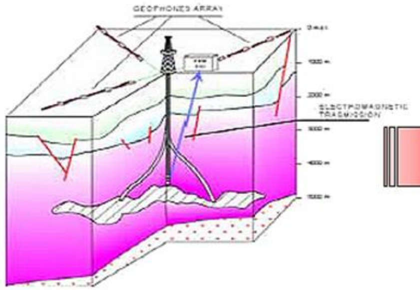
Geothermal / Oil&Gas Synergies

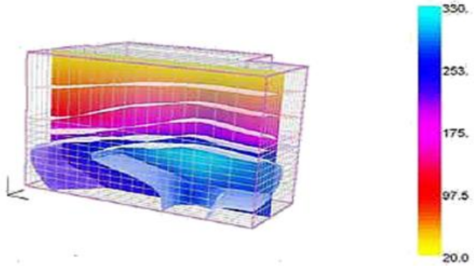
Conventional Deep Geothermal Workflow

Geology, Geophysics, Petrophysics



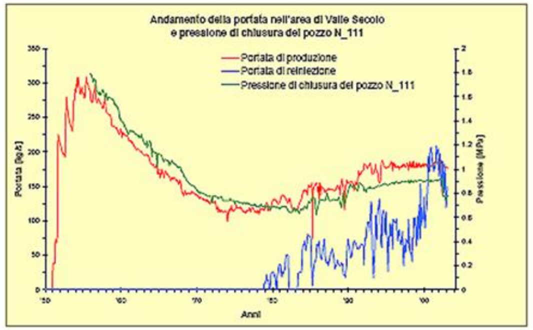
Drilling, Completions, Production Ops.





Reservoir Engineering

(after Enel, 2005)



Field Performance, Resource Management

Completions

Topics include completion design and installation, intelligent wells, sand control, hydraulic fracturing, acidizing and stimulation, and well integrity. Special interests are supported through technical sections, and peer-reviewed papers are published in both *SPE Drilling & Completions* and *SPE Production & Operations* journals. Go to Completions

Data Science and Engineering Analytics

Topics include information systems, data use and management with specializations covered in technical sections and articles published in the *Data Science and Digital Engineering* online magazine. Go to DSEA

Drilling

Covers topics from well planning and wellbore design through drilling equipment, systems and operations to casing and cementing. Special interests are supported through technical sections, and peer-reviewed papers are published in the journal *SPE Drilling & Completions*. Go to Drilling

Projects, Facilities, and Construction

Topics include processing, flow assurance and subsea systems, measurement and control, platforms and floating systems, and facilities operations. Peer-reviewed papers, as well as articles, are published in the *Oil and Gas Facilities* magazine. Go to Facilities

Health, Safety, Environment, and Sustainability

Comprises core HSE topics as well as research and sustainability issues. Specializations are covered through technical sections, workshops, publications, and international HSE conferences held in both the US and abroad. Go to HSE

Management

Topics range from strategic planning to energy economics with specializations covered in Technical Sections. Peer-reviewed papers, as well as management related articles are published in the *SPE Economics & Management* journal. Go to Management

Production and Operations

Focuses include artificial lift, well operations and optimization, surveillance and monitoring, production chemistry, well intervention and decommissioning. Peer-reviewed papers are published in the journal *SPE Production & Operations*. Go to Production and Operations

Reservoir

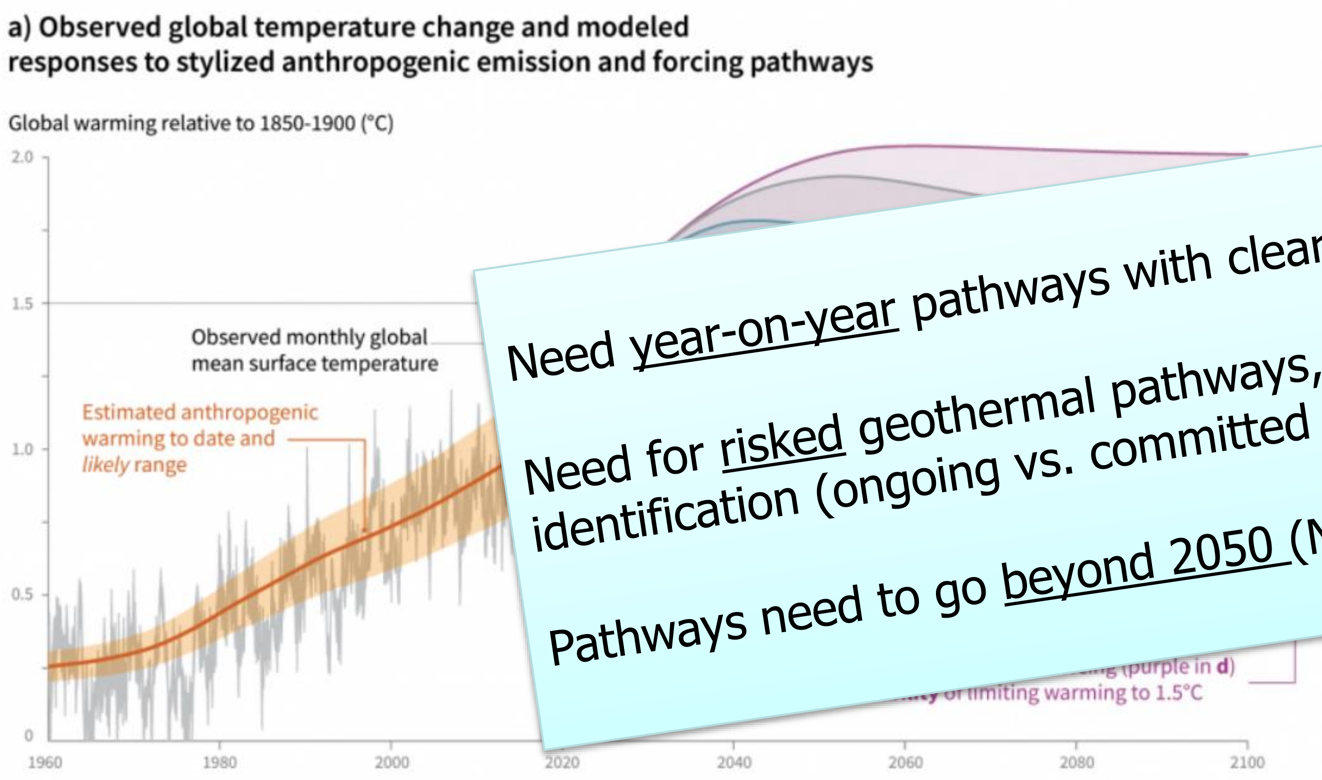
Topics range from simulation and formation evaluation to unconventionals and enhanced recovery processes. Specialized topical covered in global events and the peer-reviewed journal, *SPE Reservoir Evaluation & Engineering*. Go to Reservoir

Society of Petroleum Engineering Disciplines

PATH TO NET-ZERO

IEA's pathway to Net-Zero

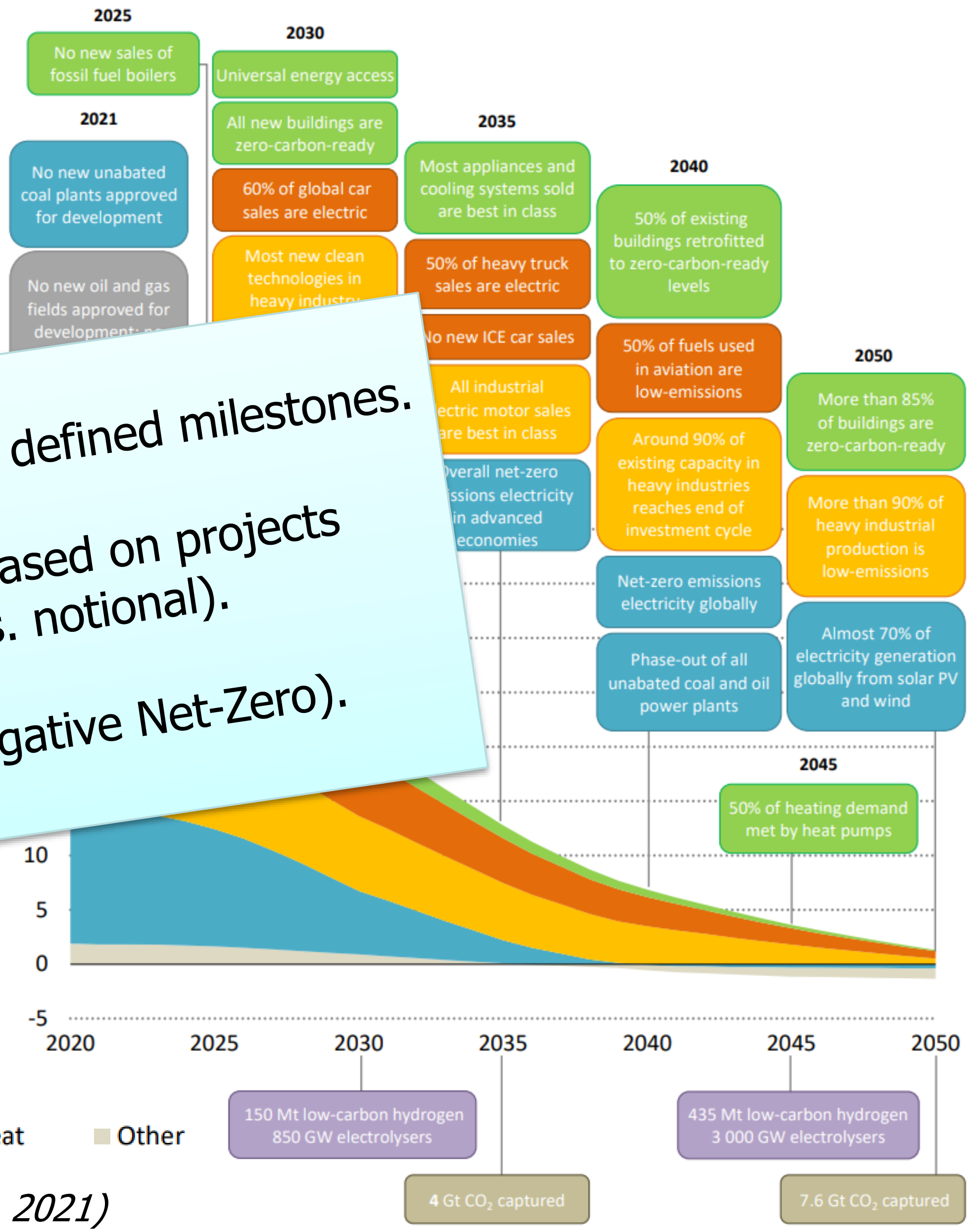
Pathways to limit global warming to 1.5 °C



Need year-on-year pathways with clearly defined milestones.

Need for risked geothermal pathways, based on projects identification (ongoing vs. committed vs. notional).

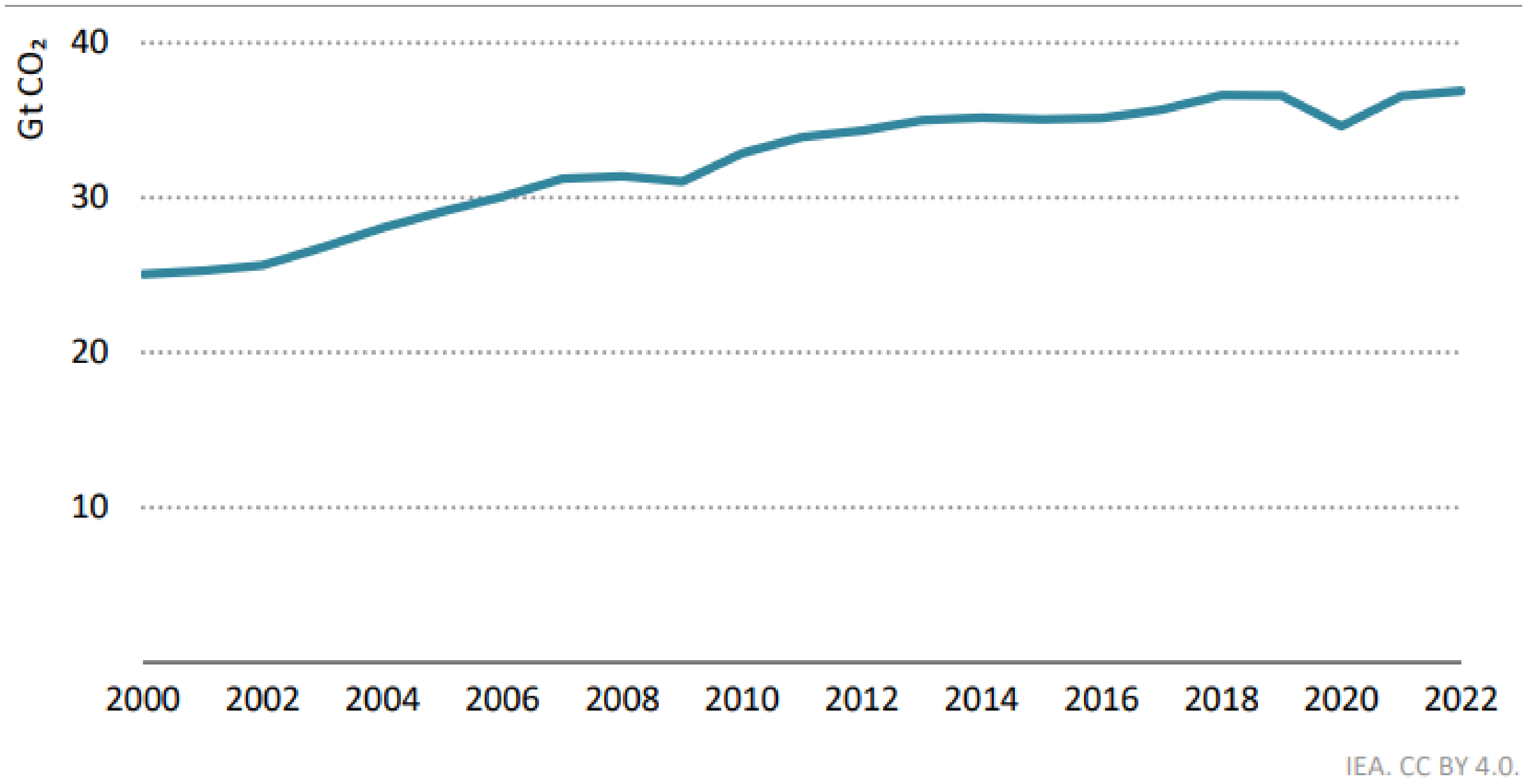
Pathways need to go beyond 2050 (Negative Net-Zero).



(IEA, 2021)

TRACKING PROGRESS

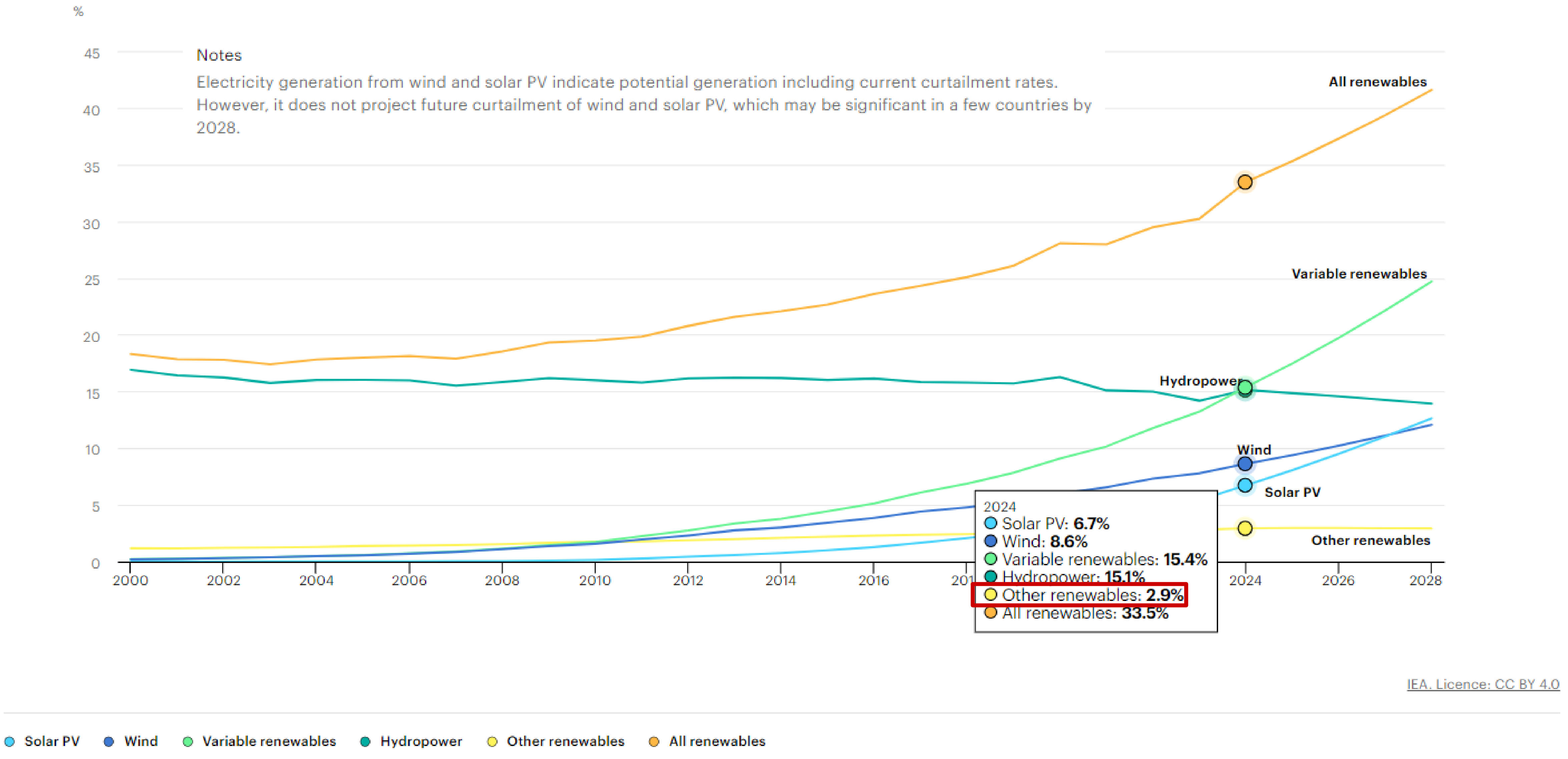
Global energy sector CO2 emissions, 2000-2022



Global energy sector emissions have not fallen in the last two years,
as envisaged in our 2021 roadmap, but instead have risen to record levels

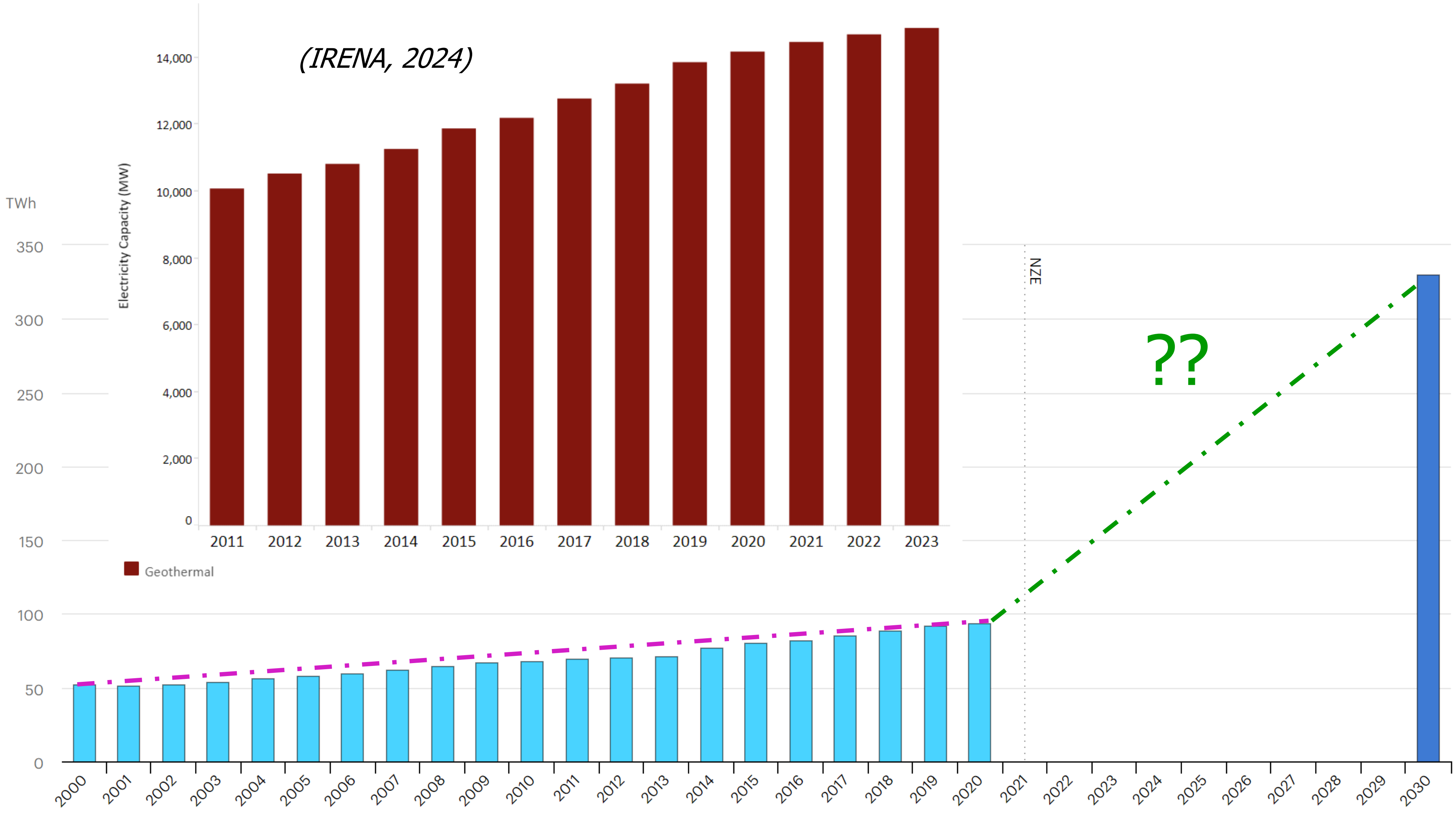
(IEA, 2023)

Global renewable power : curtailment issues



(IEA, 2023)

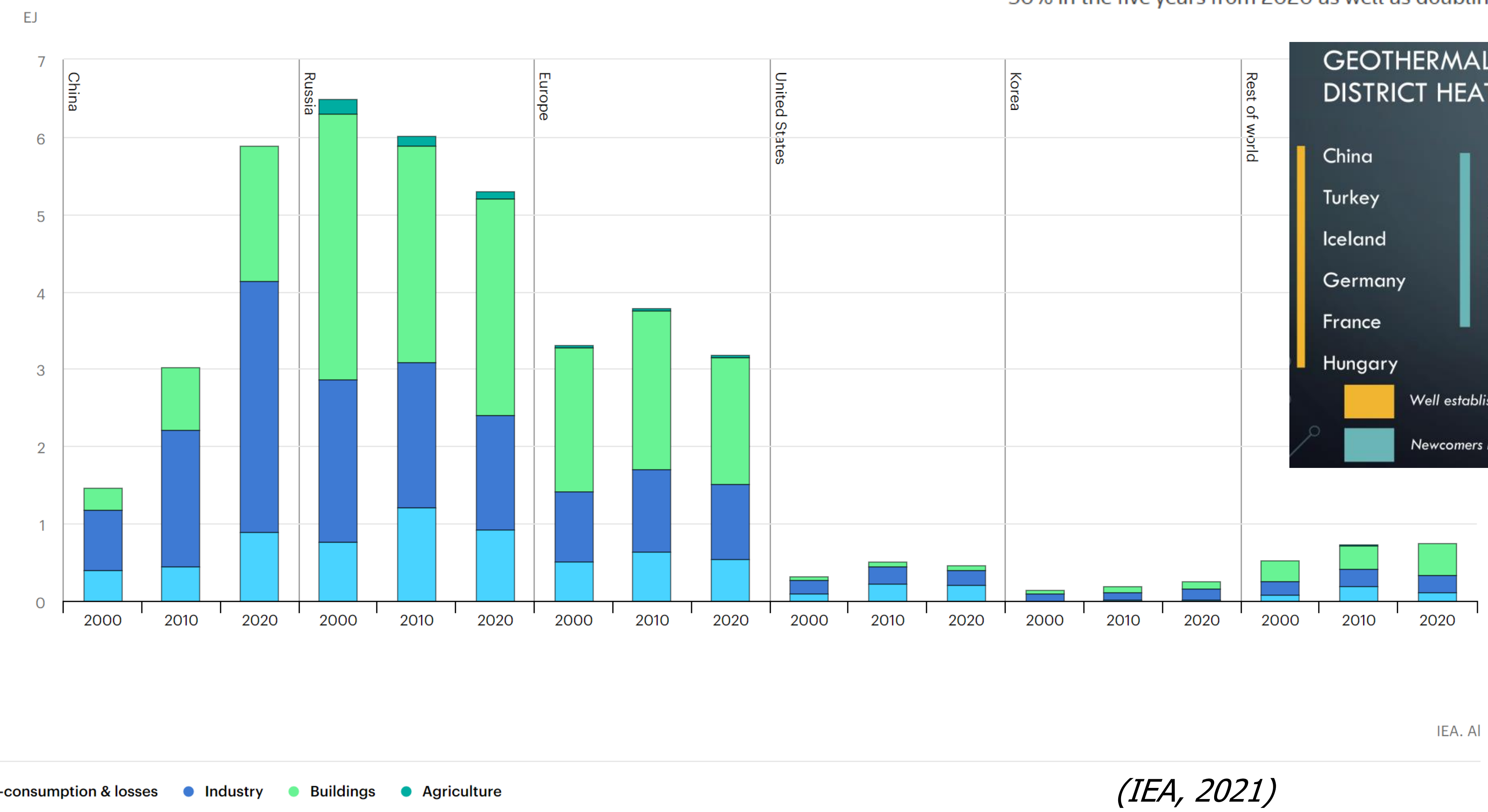
Global geothermal power: more effort needed!



(IEA, 2021)

Global District Heating (DH)

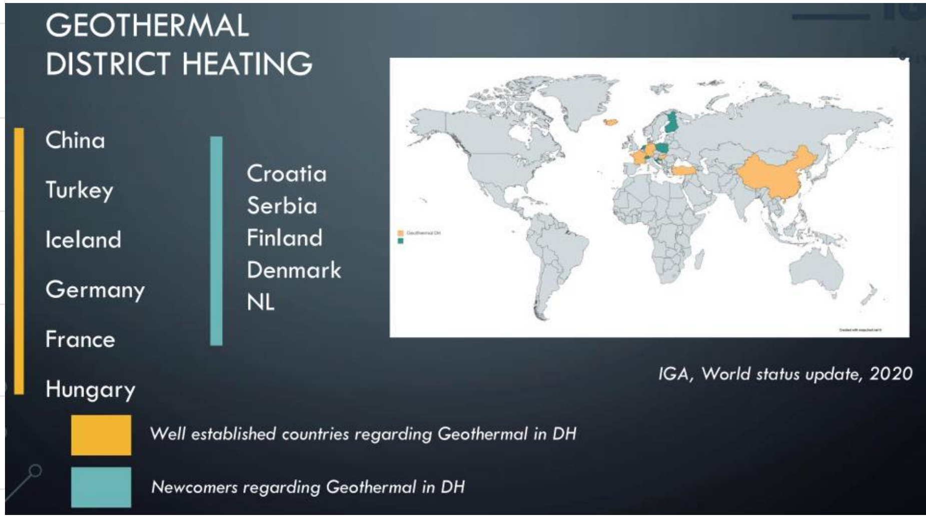
District heat production by selected region and heat delivered by sector, 2000-2020



(IEA, 2021)

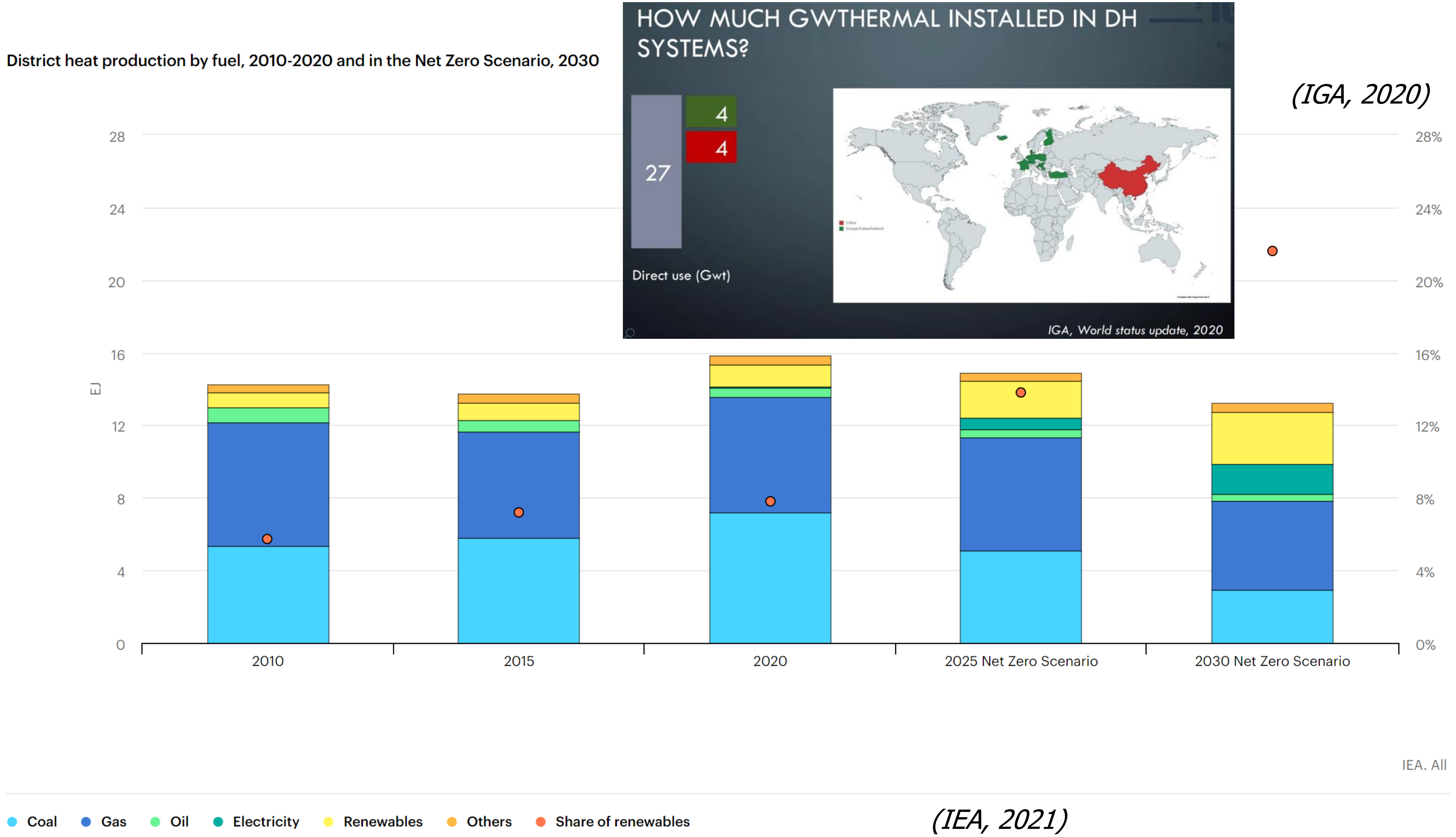
China boasts the world's largest geothermal DH network, with 200,000 km of pipework

China's National Energy Administration has proposed increasing the geothermal heating-cooling area by 50% in the five years from 2020 as well as doubling the geothermal power generation capacity.



(IGA, 2020)

DH: geothermal vs. oil & gas



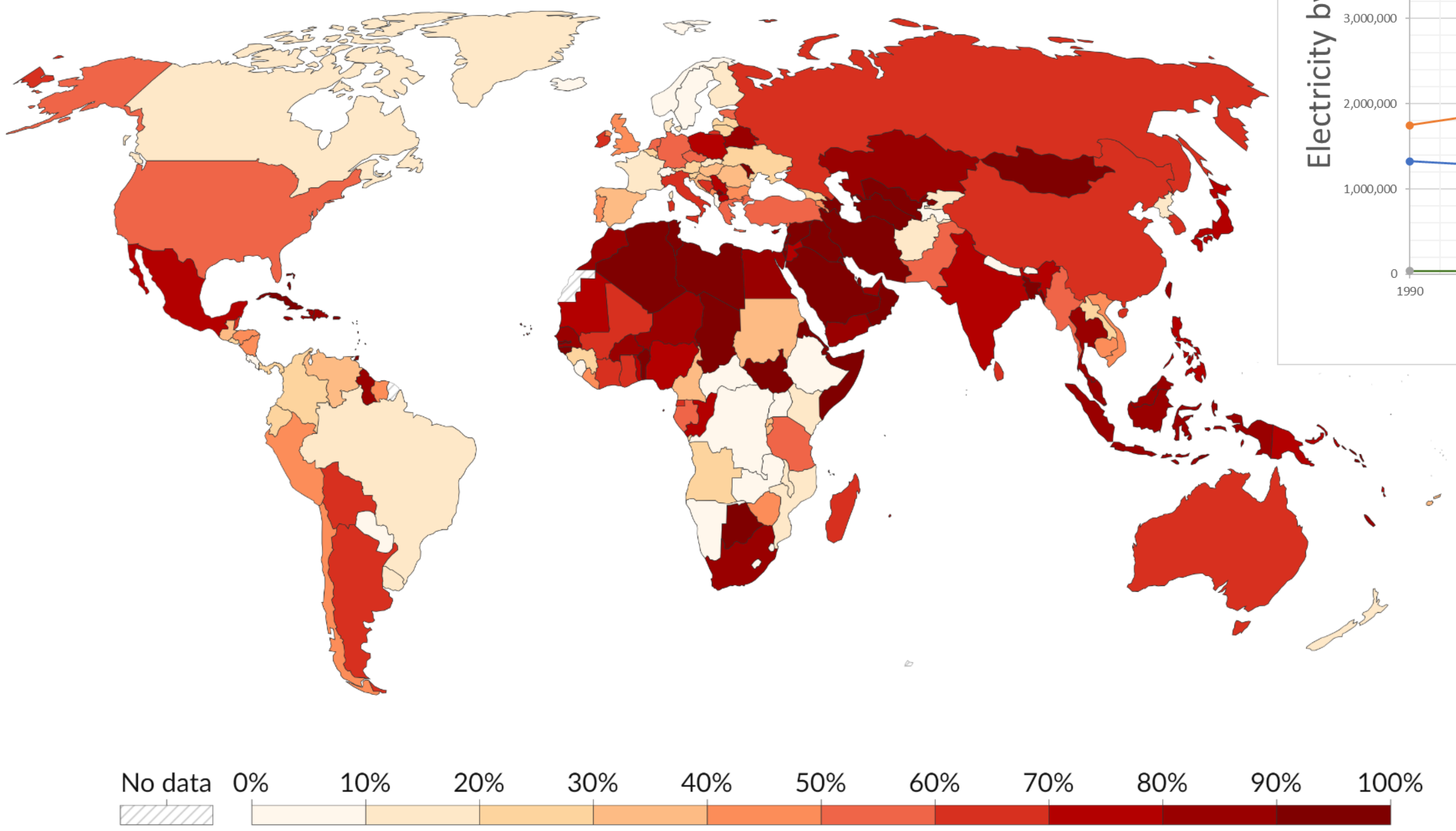
(IGA, 2020)

(IEA, 2021)

Global power: oil & gas share

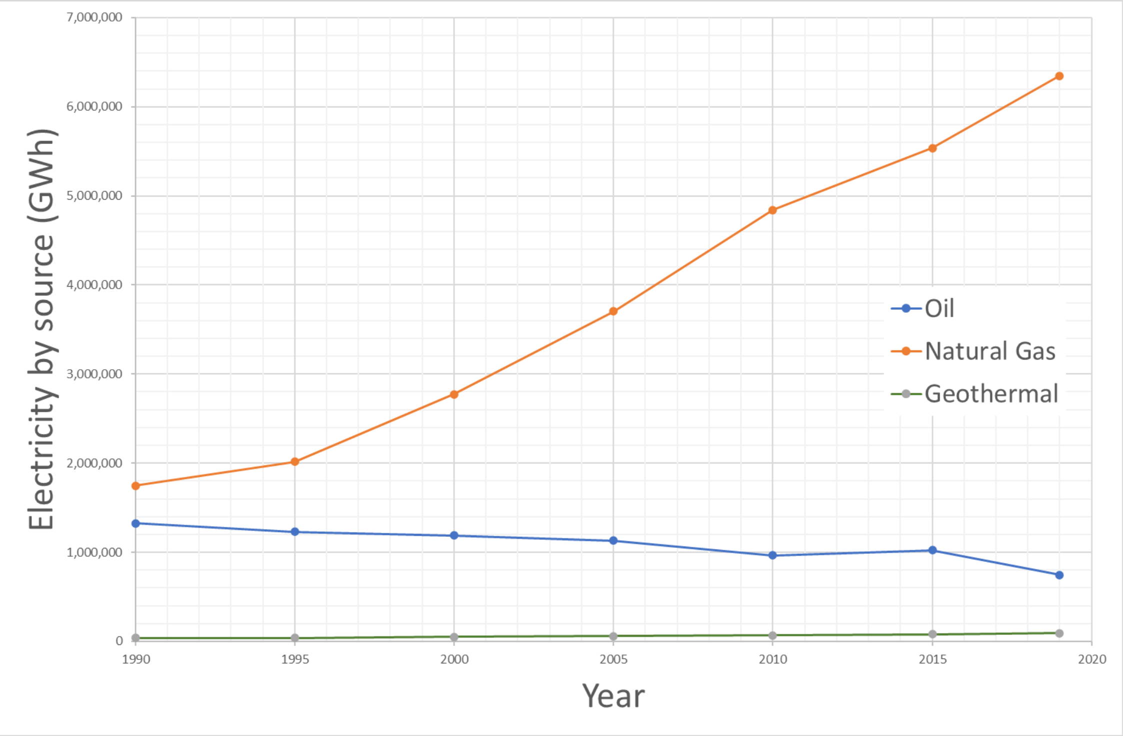
Share of electricity production from fossil fuels, 2022

Measured as a percentage of total electricity.



Data source: Ember - Yearly Electricity Data (2023); Ember - European Electricity Review (2022); Energy Institute - Statistical Review of World Energy (2023)

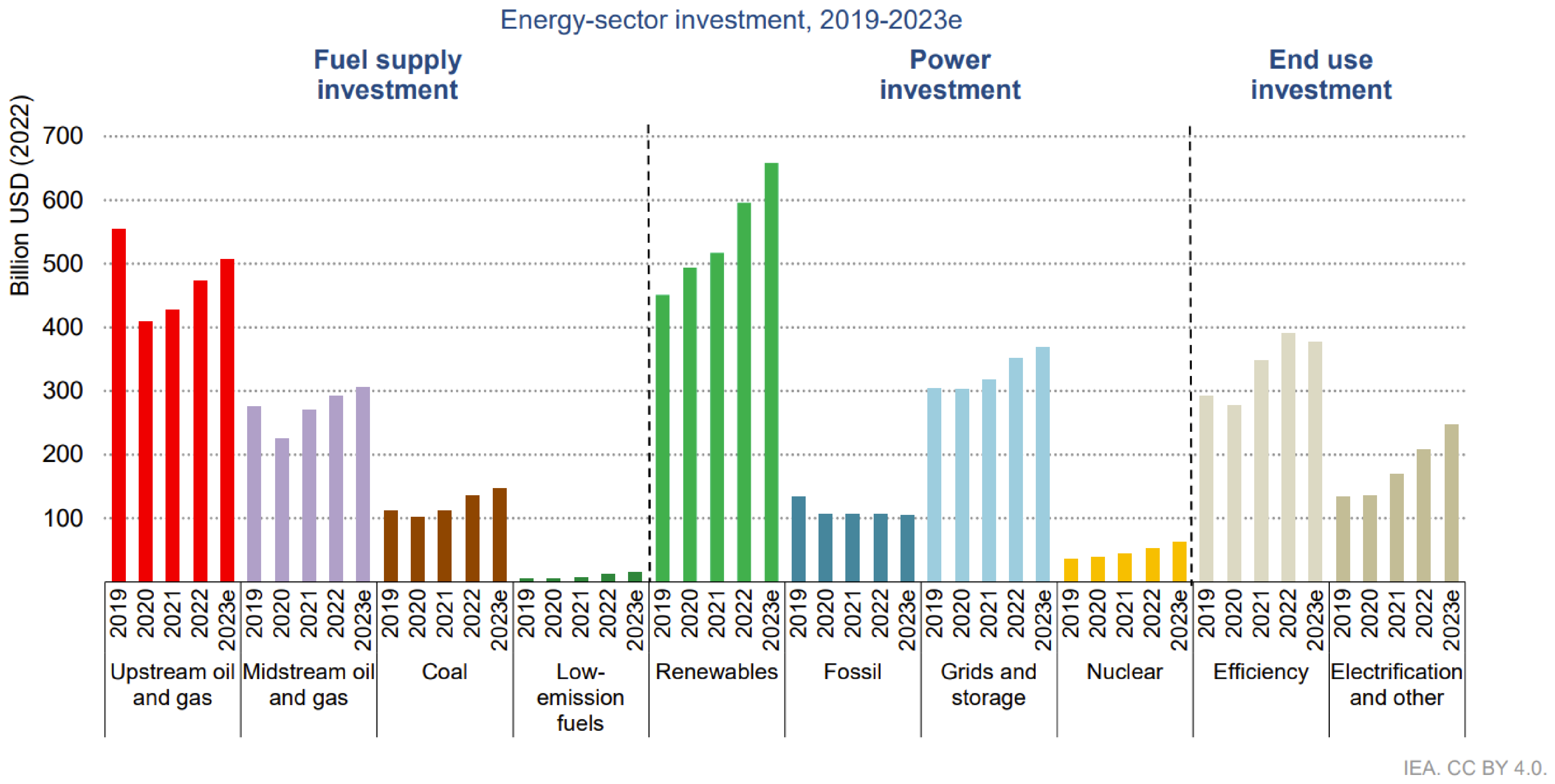
OurWorldInData.org/energy | CC BY



(data after IEA, 2020)

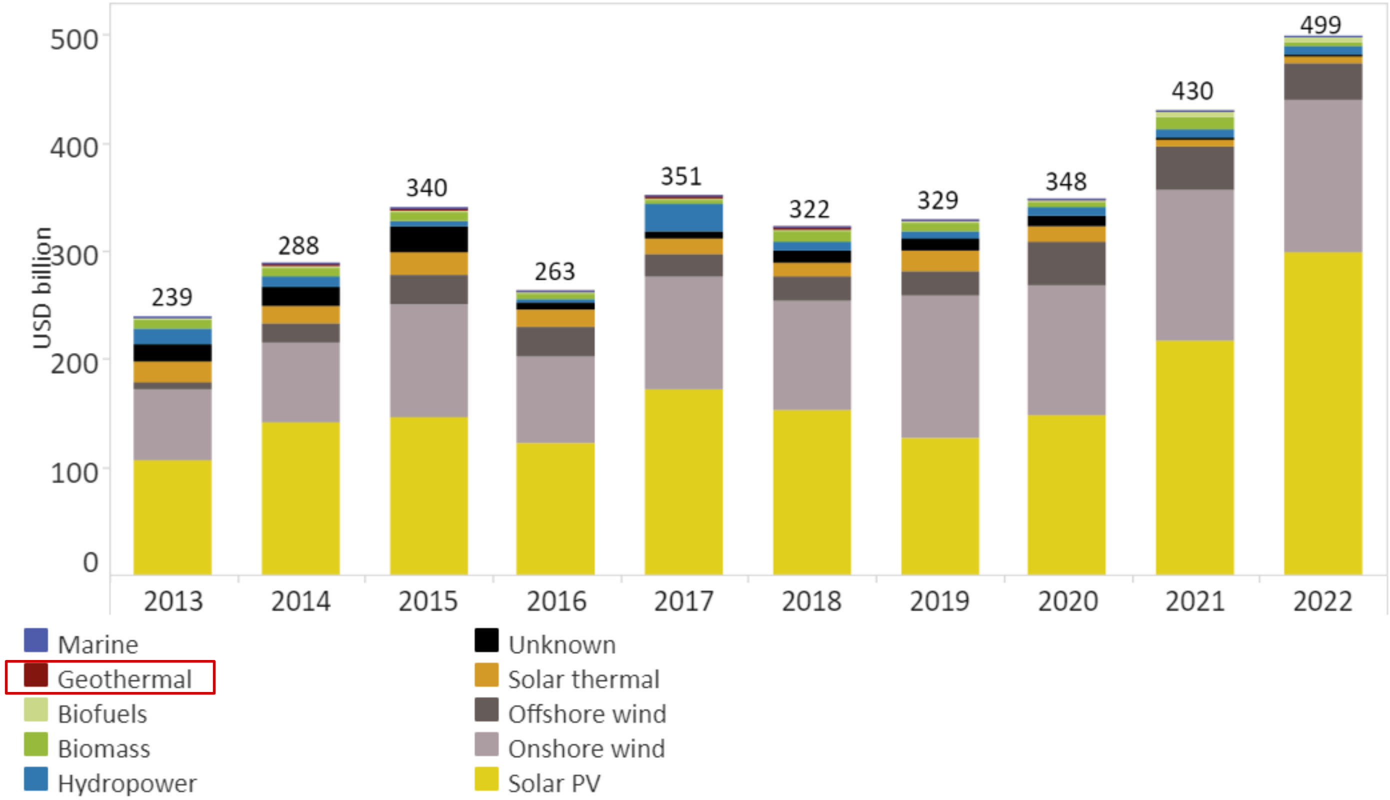
CAN INVESTMENT BE SHIFTED?

Global energy investment by sector, 2019-2023



Notes: "Low-emission fuels" include modern liquid and gaseous bioenergy, low-emission hydrogen and low-emission hydrogen-based fuels; "Other end use" refers to renewables for end use and electrification in the buildings, transport and industrial sectors. The terms grids and networks are used interchangeably in this report and do not distinguish between transmission and distribution; 2023e = estimated values for 2023..

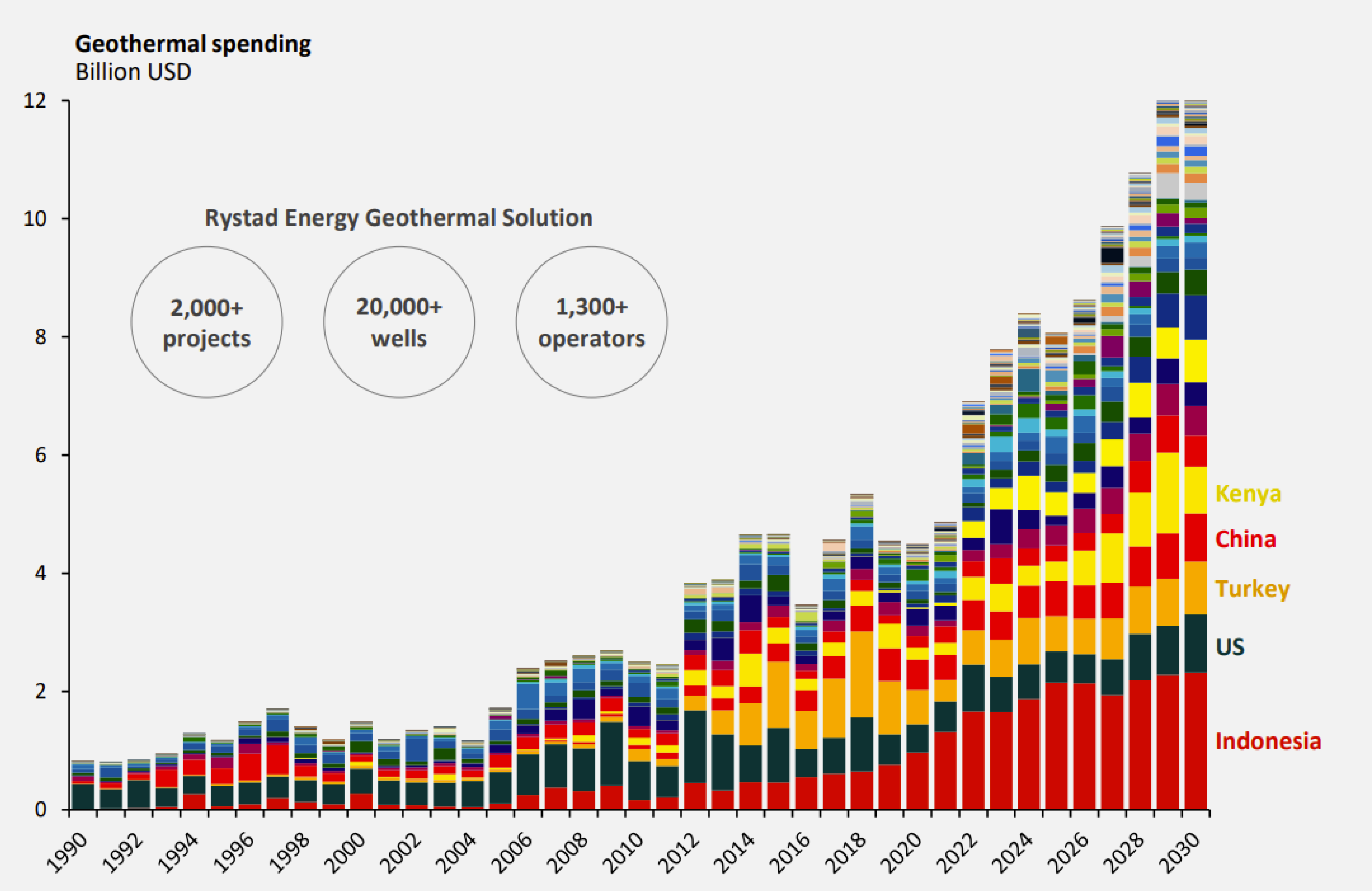
Renewable energy investment by sector, 2013-2022



During 2013-2022, solar PV and onshore wind continued to consolidate their dominance, attracting, respectively, 46% and 32% of global renewable energy investments. Investments in offshore wind has picked up, attracting 8% of the total, followed by solar thermal at 5%. Other renewable energy technologies (including hydropower, biomass, biofuels, geothermal and marine energy) altogether attracted only 7% of total investment in 2013-2022, with hydropower making a relatively significant portion of the total. More funds need to flow to less mature technologies that have a crucial role to play in the energy transition. The concentration of investments in solar and wind technologies further increased in 2022 as they attracted 95% of the overall investment.

Source: IRENA and CPI (2023), Global landscape of renewable energy finance, 2023, International Renewable Energy Agency, Abu Dhabi. https://www.irena.org/Publications/2023/Feb/Global-landscape-of-renewable-energy-finance-2023

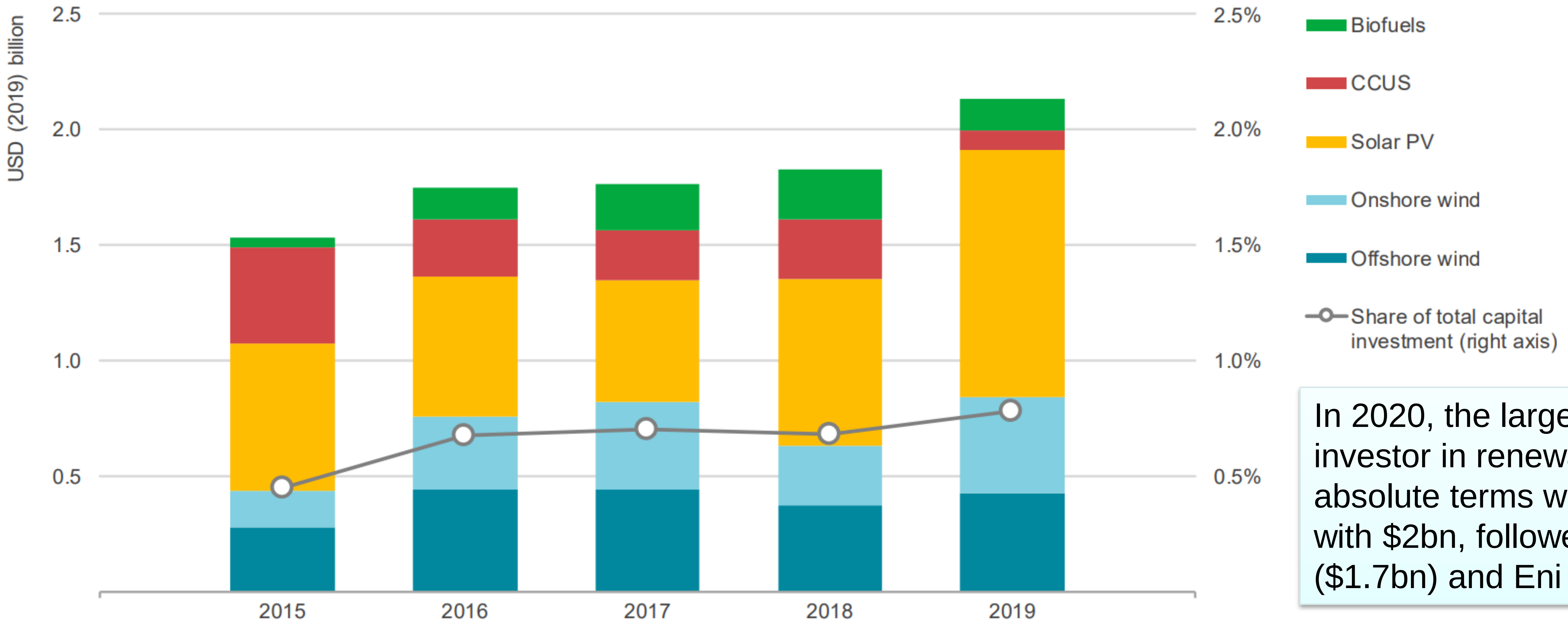
Global investment: geothermal



Source: Rystad Energy Geothermal Solution

Rystad Energy Geothermal Whitepaper – October 2022

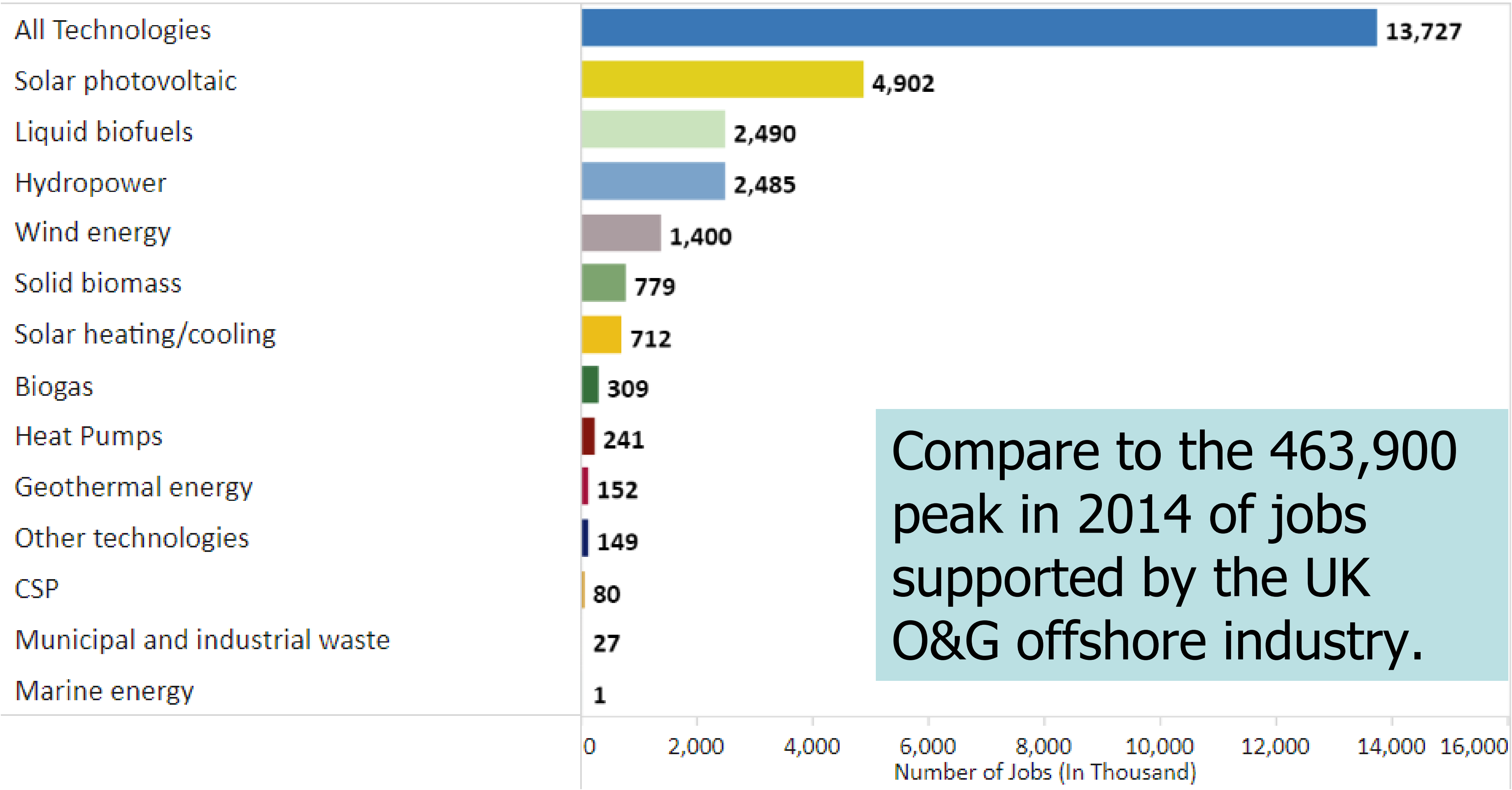
Capital investment by Majors and selected other companies in new projects outside oil & gas supply



In 2020, the largest single investor in renewables in absolute terms was Shell with $2bn, followed by Total ($1.7bn) and Eni ($1.6bn).

Notes: Capital investment is measured as the ongoing capital spending in new capacity from when projects start construction and are based on the owner's share of the project. Companies include the Majors and selected others (ADNOC, CNPC, CNOOC, Equinor, Gazprom, Kuwait Petroleum Corporation, Lukoil, Petrobras, Repsol, Rosneft, Saudi Aramco, Sinopec, Sonatrach). CCUS investment is in large-scale facilities; it includes developments by independent oil and gas companies in Canada and China and capital spend undertaken with government funds.

Jobs: geothermal



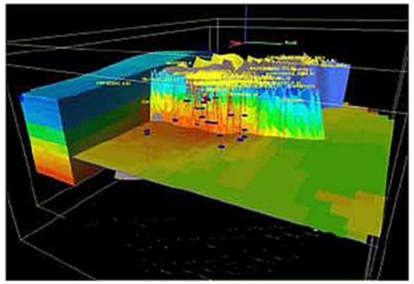
Source IRENA and ILO (2023), Renewable energy and jobs: Annual review 2023, International Renewable Energy Agency, Abu Dhabi and International Labour Organization, Geneva. Data are principally for 2022, with some dates for 2021 and a few instances in which only earlier information is available. 'Other Technologies' include jobs not broken down by individual renewable energy technologies.

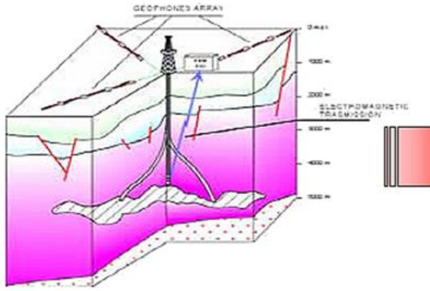
SECTOR SYNERGIES STILL STAND!
…PRIORITIES?
(commensurate with expectations)

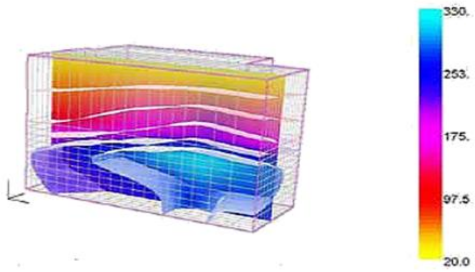
Geothermal / Oil&Gas: the synergies still stand!

Geology, Geophysics, Petrophysics

Drilling, Completions, Production Ops.







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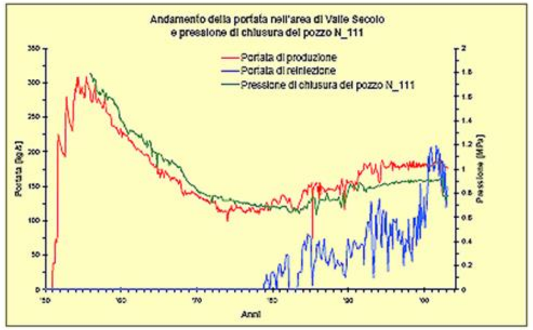

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Society of Petroleum Engineering Disciplines

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Resource assessment standards e.g., prospect chance of success

Supplementary Specifications for the Application of the United Nations Framework Classification for Resources (Update 2019) to Geothermal Energy Resources

Prepared by the United Nations Framework Classification for Resources Ad Hoc Committee of the International Geothermal Association

Summary

This document supersedes and replaces the Specifications for the Application of the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC-2009) to Geothermal Energy Resources, which were released on 30 September 2016.

This document outlines the Supplementary Specifications for the Application of the United Nations Framework Classification Resources (Update 2019) (UNFC (2019)) to geothermal energy resources. Its intended use is in conjunction with UNFC (2019). Given the updates incorporated in UNFC (2019), there is no longer a requirement to use this document in conjunction with the Specifications for the Application of UNFC-2009 to Renewable Energy Resources, which were also released on 30 September 2016, as they are no longer in use.

Oil & gas:

$$P_g = P_{Source} \times P_{Dynamics} \times P_{Trap} \times P_{Reservoir}$$

$$P_d = P_{Economics} \times P_{Technol...} \times P...$$

Geological ch...

Need to encourage disclosure of:

- Chance of success
- Degree of confidence in the estimate of the quantities of products from the project (e.g., P10, P50, P90)
- Risked quantities

Would facilitate shift of investment…

Geothermal:

(but not necessar...

for closed-loop sy...

...	70 %
...ability	70 %
Fluid Chemistry	90%
COMBINED : Probability of Discovery	~ 44 %

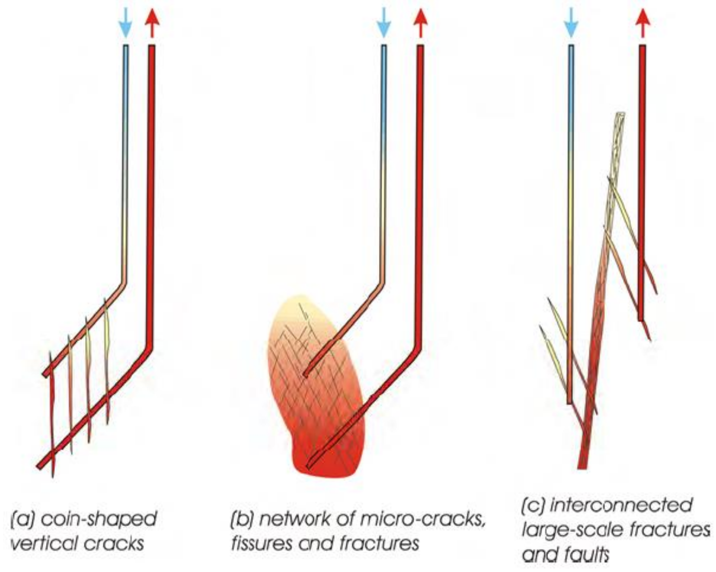
(Ussher, 2019)

Geothermal specifications update completed and operational since **25-Oc-22**!

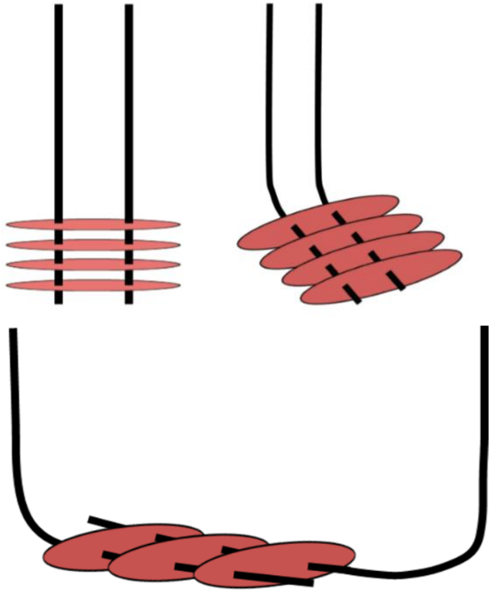
CCS:

"A subsurface body of rock with sufficient porosity and permeability to store and transmit fluids and characterized by a hydraulically connected pressure system" + *"overlying cap rock or seal"* + *"retention of injected fluid through one or more trapping mechanisms"*. *(UNECE, 2016)*

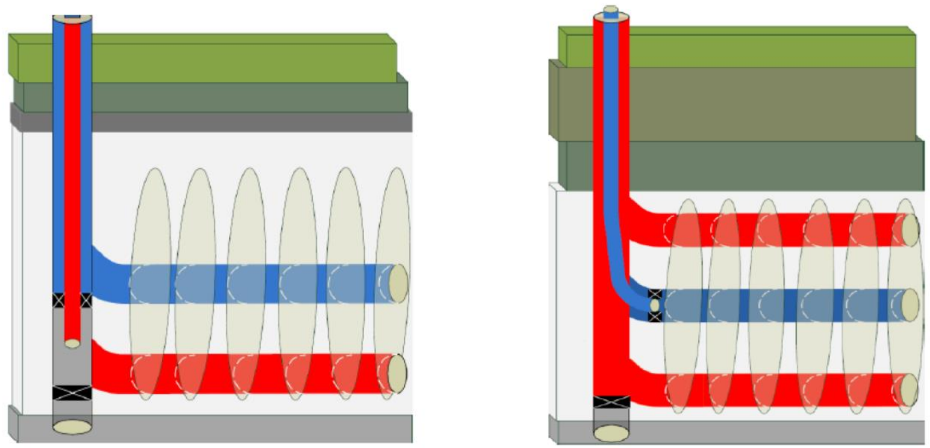
Unconventional ‘EGS’ well designs



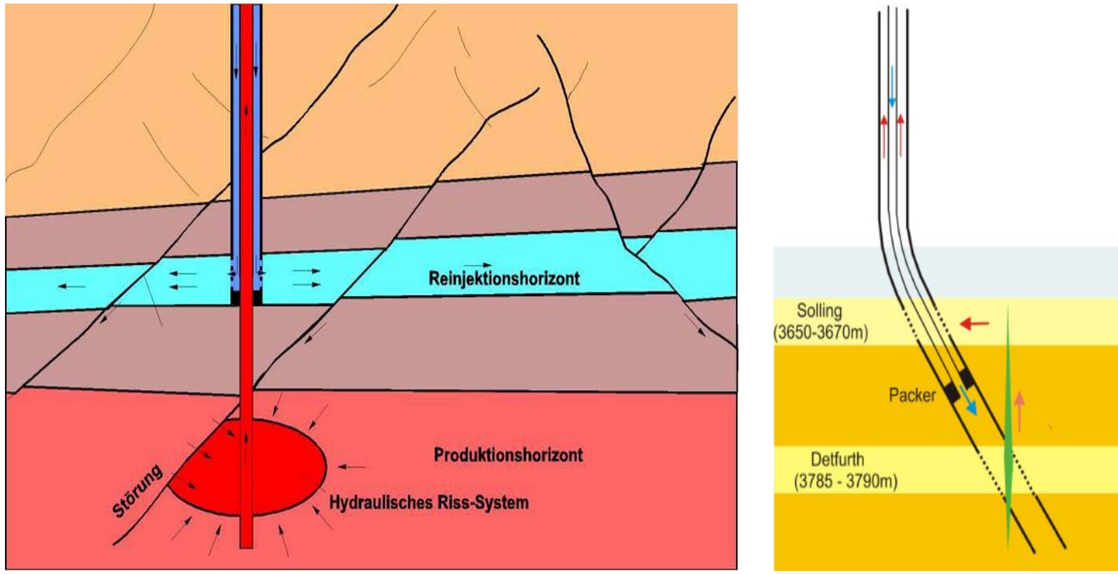
(Clauser, 2006)



(Shiozawa and McClure, 2014)

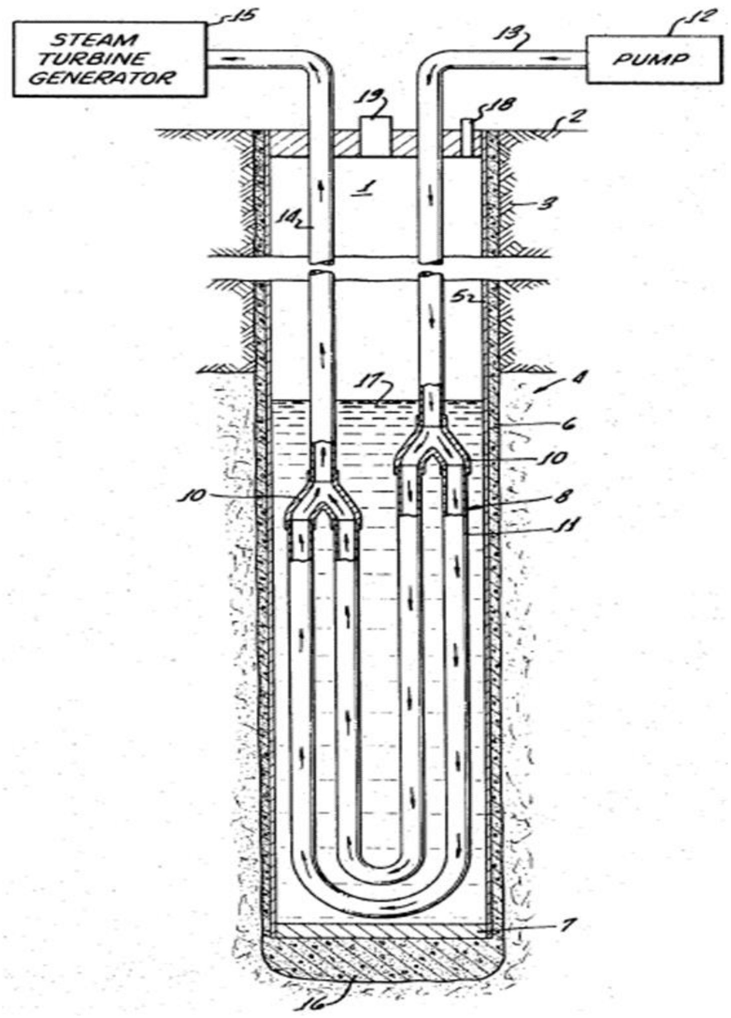


(Gedzius and Teodoriu, 2011)

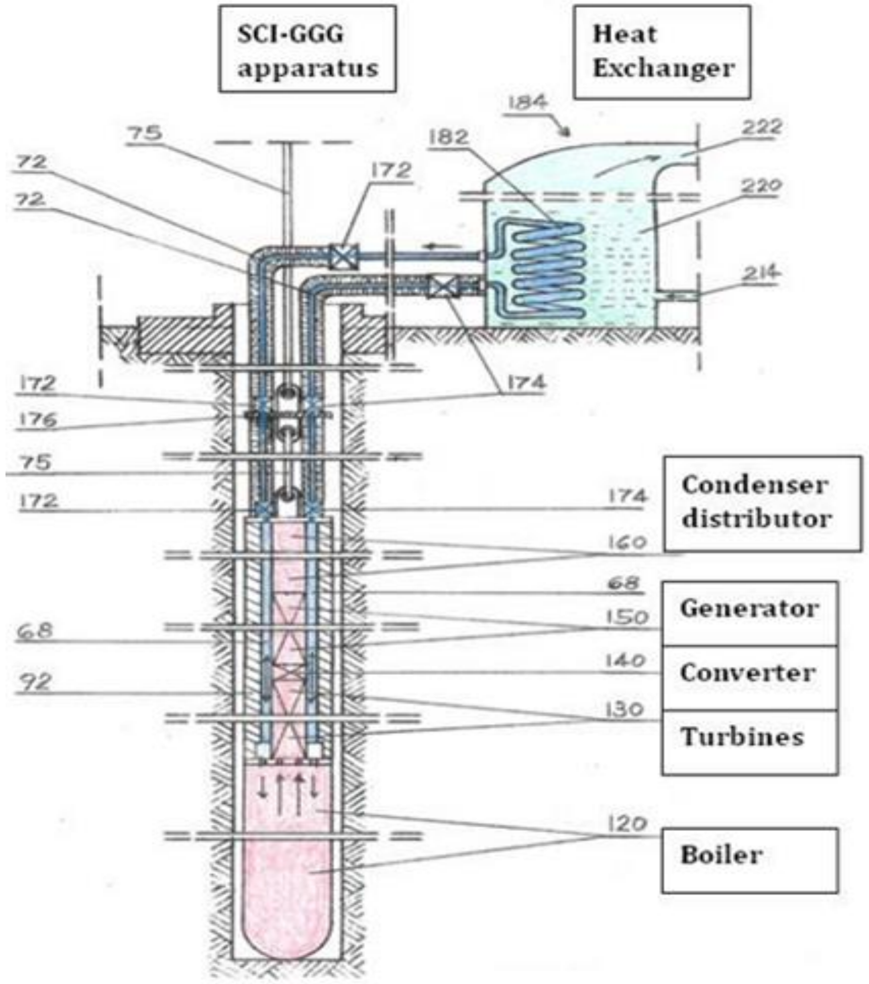


(Jung et al., 2006, left, and Torsten et al., 2010, right)

Unconventional closed-loop designs (1)



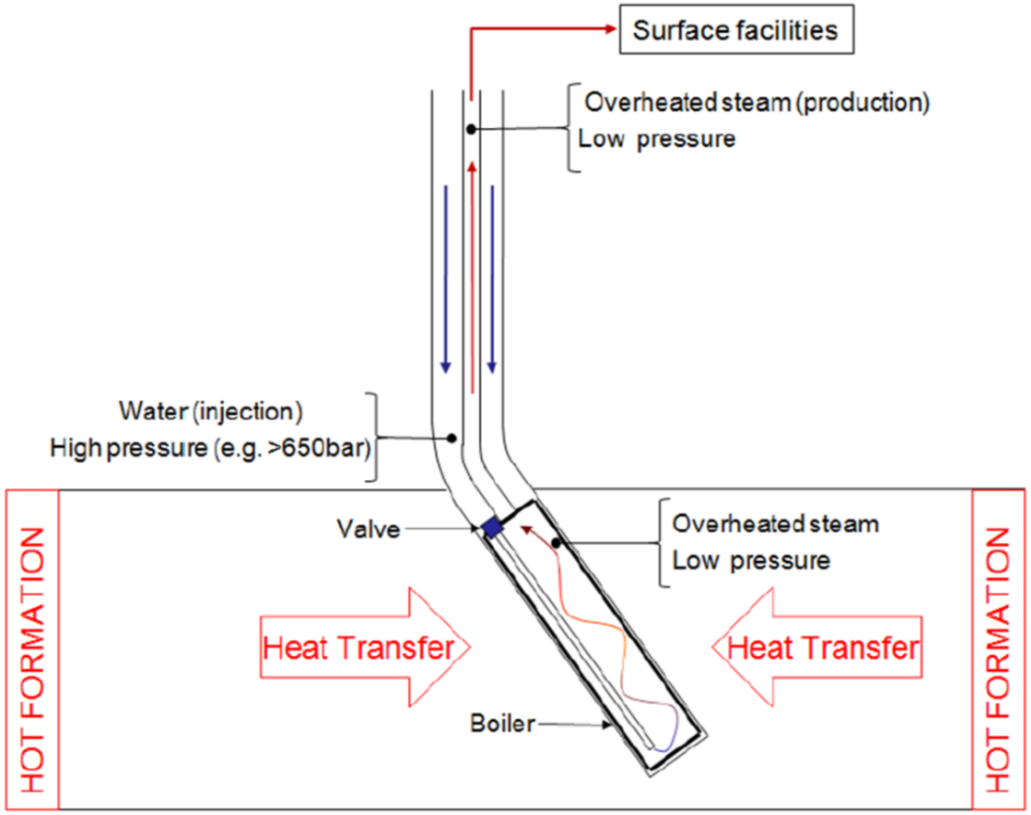
(Van Huisen, 1969)



(Lakic, 2010)

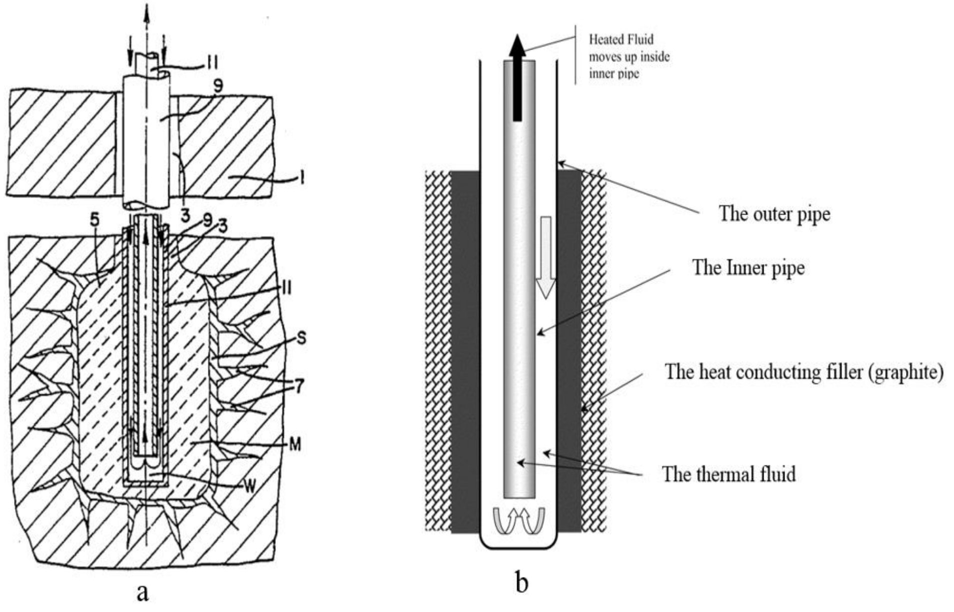
Unconventional closed-loop well designs (2)

Artificial Geyser



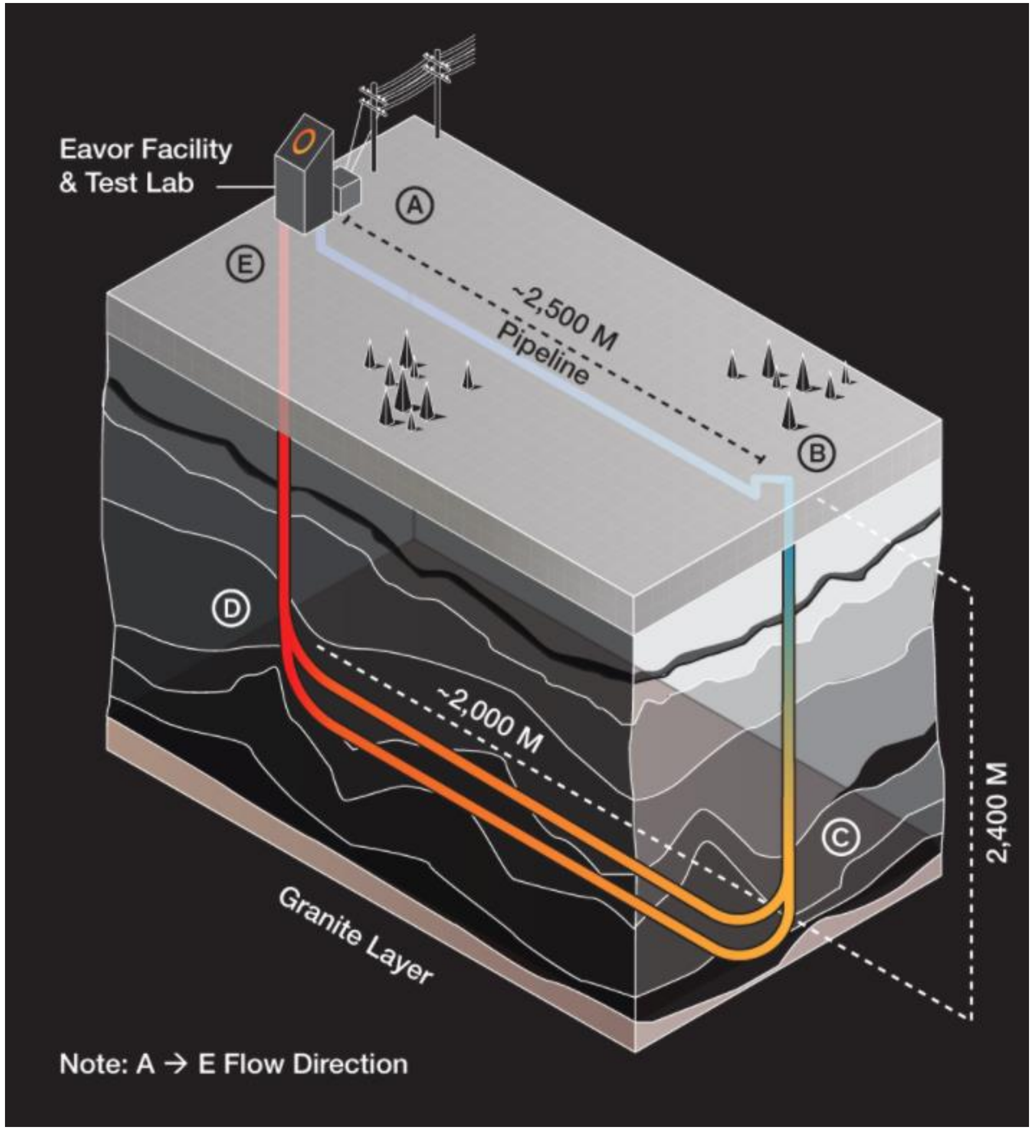
(Bierenriede, 2011; Heller and Teodoriu, 2013; Heller et al., 2014; Teodoriu et al., 2015)

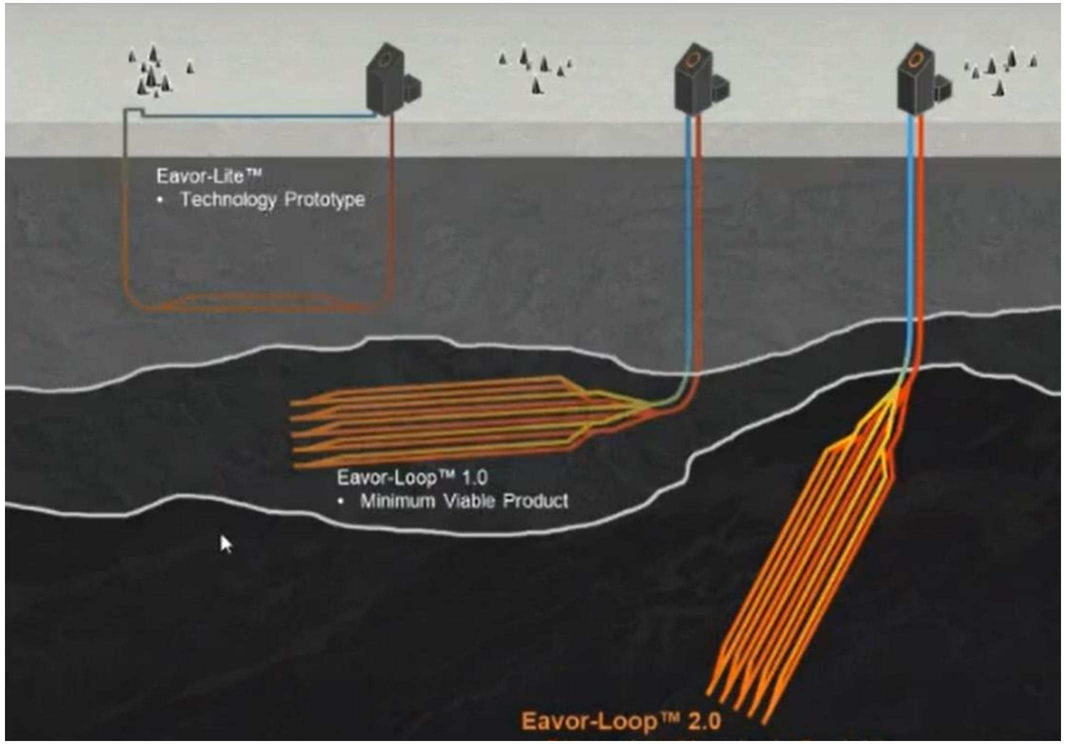
Thermally enhanced downhole designs



(Büchi, 1990, (a), and Hara, 2011, (b))

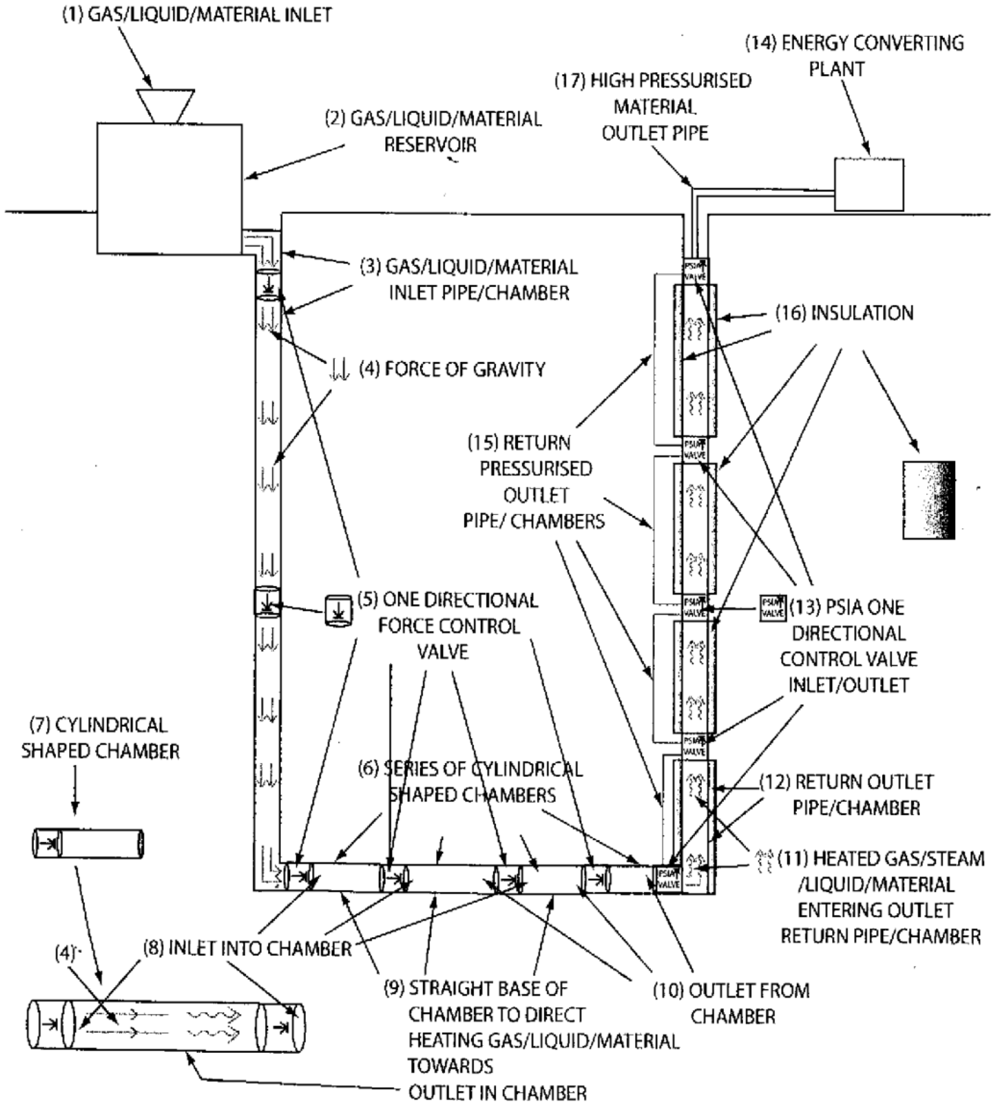
‘AGS’ (e.g., Eavor)

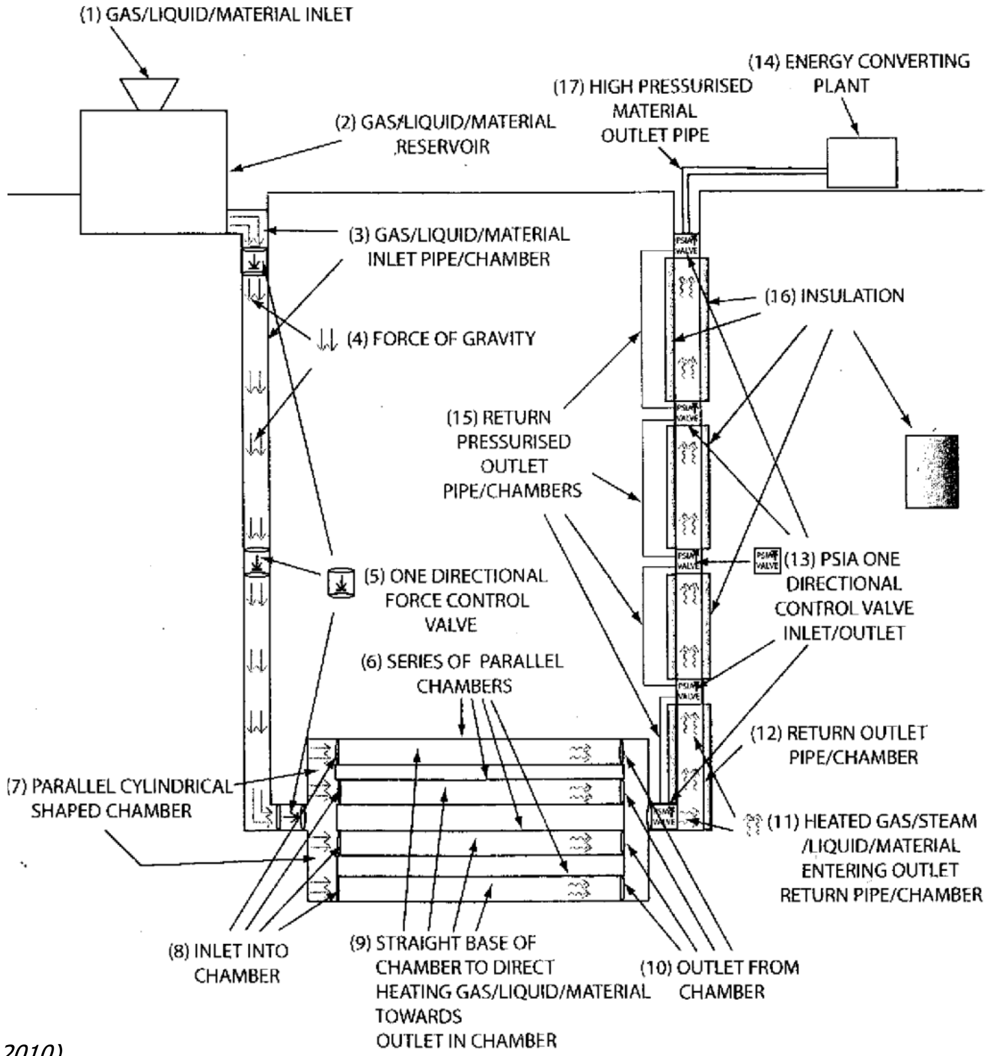




(Eavor, 2021)

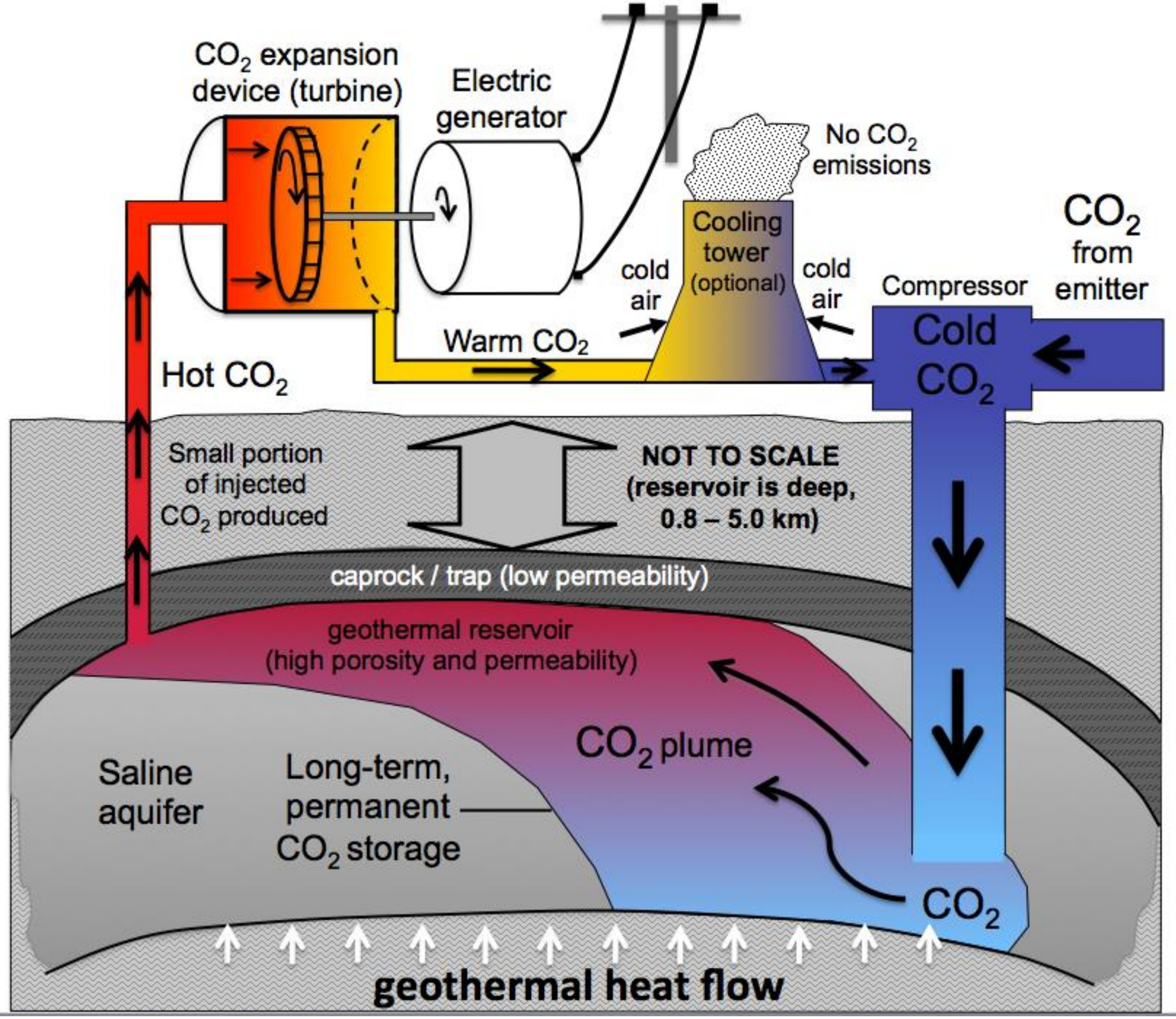
…and pre-Eavor



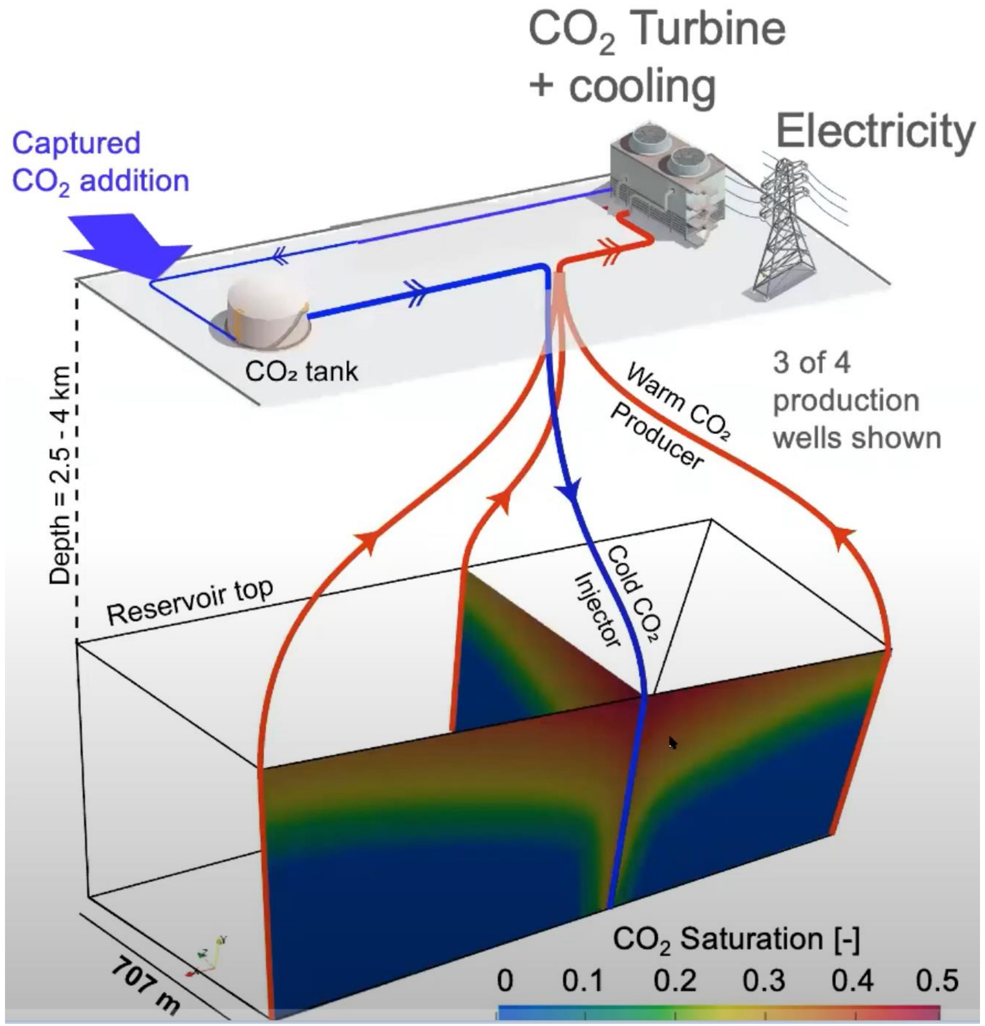


(Isaakidis, 2010)

CO_2-Plume Geothermal Systems



(Saar & Randolph, 2012)



(Saar, 2021)

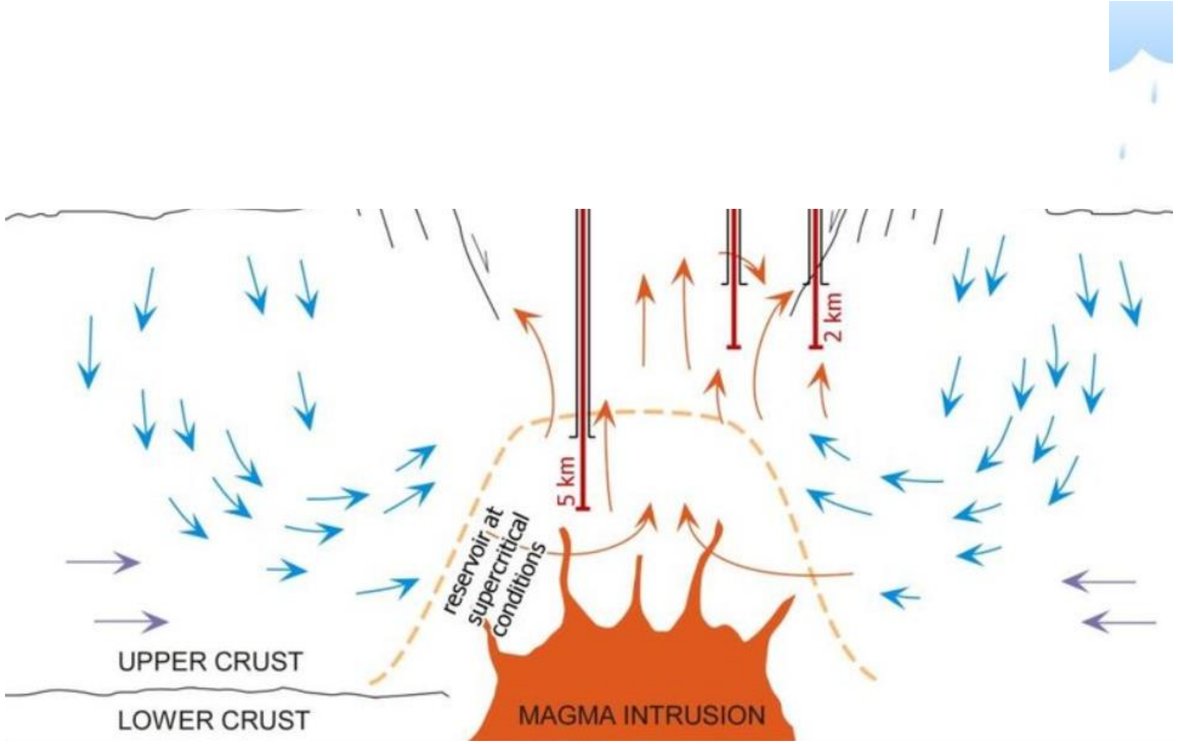
Supercritical resources

Pure water: T>374∘C and P>22.064 MPa

Pioneering projects, e.g. the Icelandic Deep Drilling Project.

SC geothermal fluids have high enthalpy per unit mass, i.e. **up to a tenfold increase in power generation**.

Research projects located in active volcanic areas in Japan, New Zealand, Italy, Iceland, USA and Mexico.



Also, 'super-hot EGS'…

Repurposing oil & gas wells…

Repurpose hydrocarbon wells …and delay decommissioning

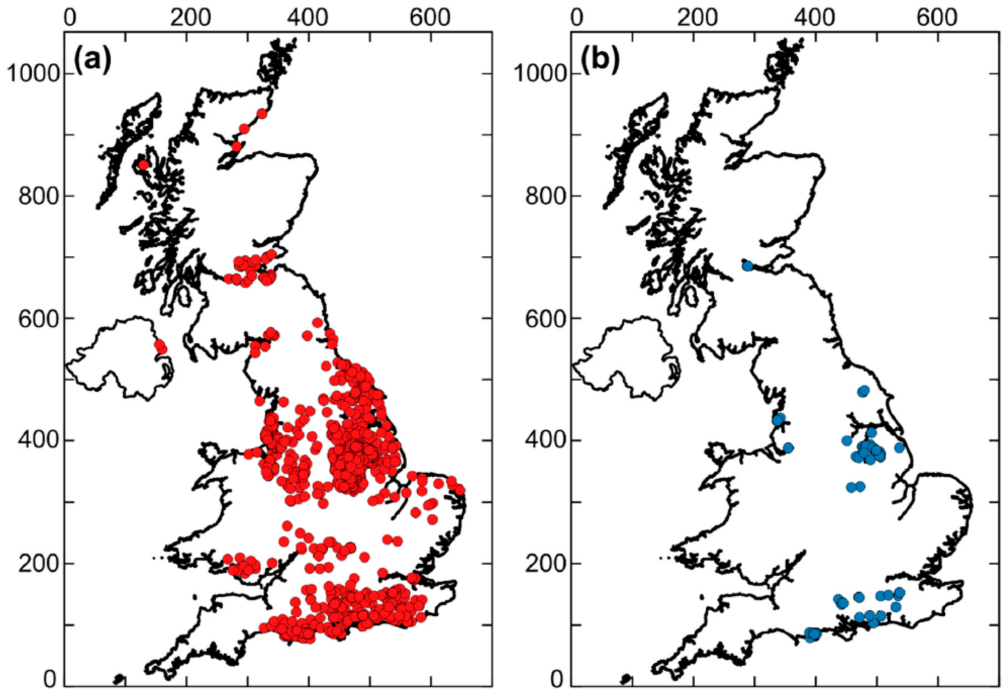


Figure 3. UK onshore hydrocarbon wells with OGA records: (a) all UK onshore hydrocarbon wells; (b) operating wells selected as potential candidates for geothermal repurposing. British National Grid co-ordinates (north and east) are in 100 km intervals.

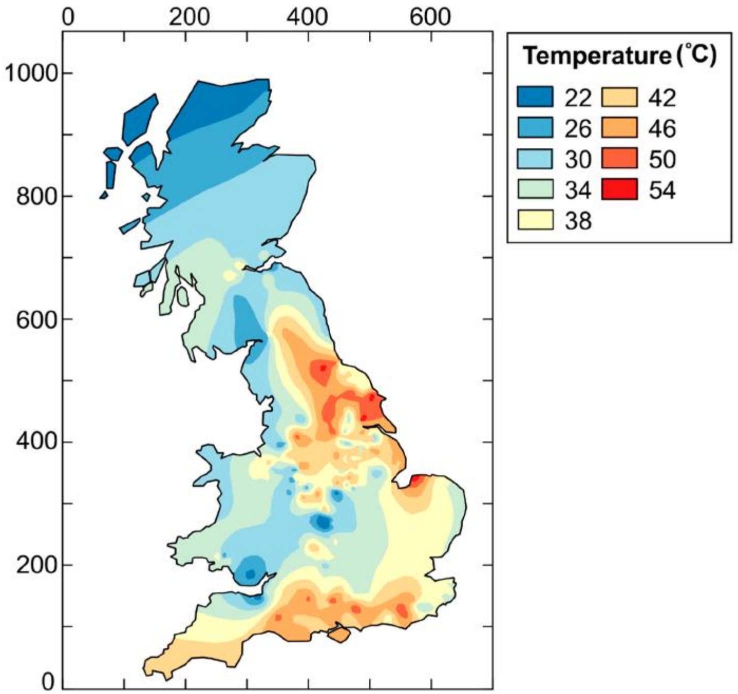
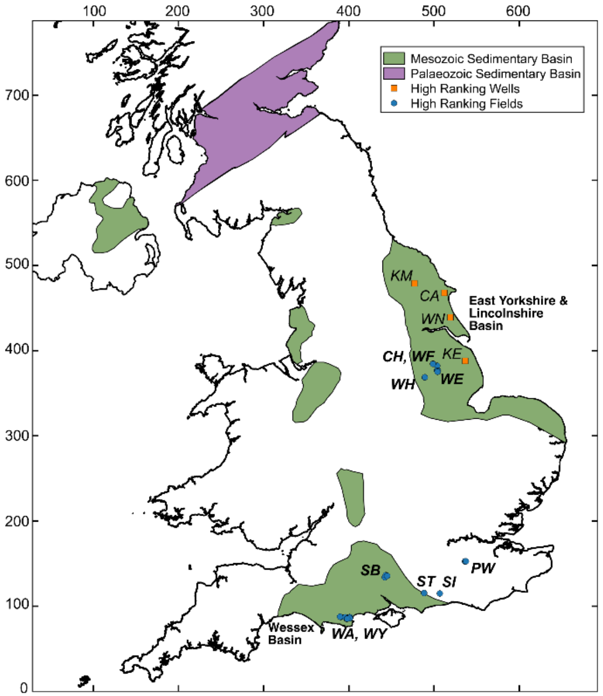


Figure 4. Regional temperature variation at 1 km depth across the UK, modified after [51]. British National Grid co-ordinates (north and east) are in 100 km intervals.

(Wastson et al., 2020)

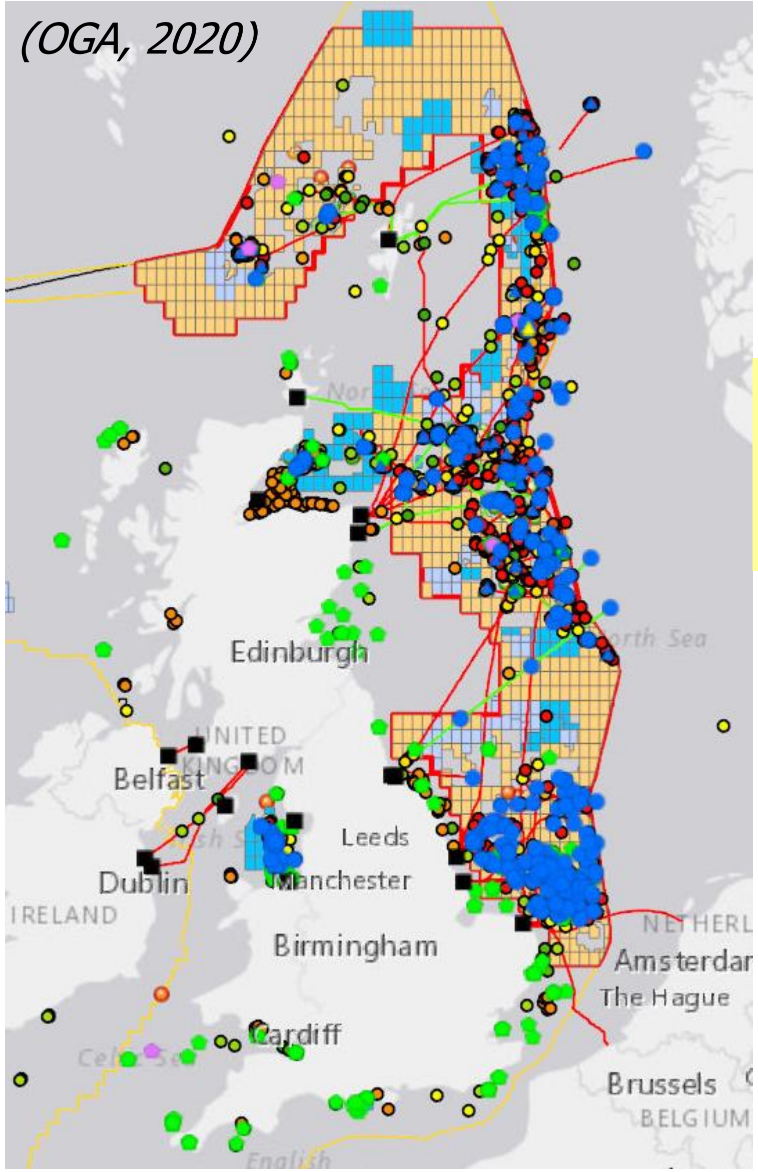


Field	BNG Reference	Production (m^3 year^{-1})	BHT (°C)	Wells
Wytch Farm *(WY)*	SY 958 852	18,566,023	65	118
Stockbridge *(SB)*	SU 423 339	130,779	51	8
Welton *(WE)*	TF 036 752	50,262	52	18
Wareham *(WA)*	SY 898 872	35,869	44	5
Palmer's Wood *(PW)*	TQ 364 526	34,852	42	6
Storrington *(ST)*	TQ 069 149	17,530	55	2
Cold Hanworth *(CH)*	TF 037 822	15,458	72	4
Singleton *(SI)*	SU 884 154	11,820	58	6
Whisby *(WH)*	SK 893 688	11,461	43	4
West Firsby *(WF)*	SK 989 845	8797	66	4

Onshore vs. offshore

Power vs. heat vs. CHP

…need to think full LCA / Cradle-to-Grave



- BUOY
- FPSO
- LOADING BUOY
- MONITOR BUOY
- OTHER SURFACE
- PLATFORM
- SBM
- TERMINAL

Decommissioning liabilities

~320 fixed installations offshore
UK >44 bn boe recovered
(*NAO, 2019*)

Estimated cost of decom for UKCS over next two decades:
£44.5bn *(NSTA, 2022)*

Cradle-to-cradle if infrastructure can be reused?
But which infrastructure, and for how long?
Decom liabilities if 'new use' of oil & gas asset?

Conclusions

- Plenty of geothermal / oil&gas synergies (not a new fact!).
- Need for risked geothermal pathways, based on projects identification (ongoing vs. committed vs. notional).
- Geothermal progress not currently on track – opportunities?
- Opportunities (commensurate with expectations) can shift investment.


University of Glasgow
Thank you!
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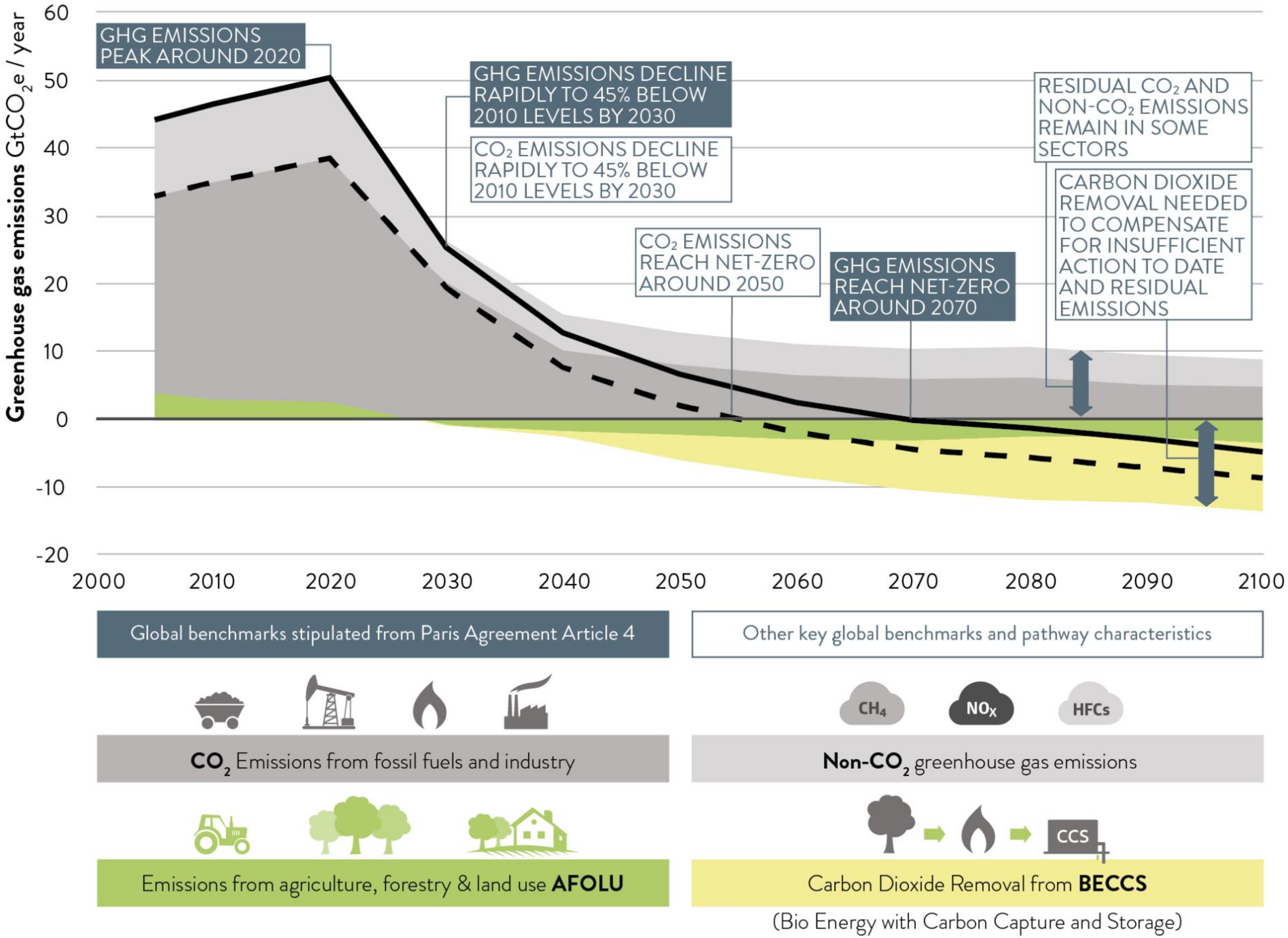
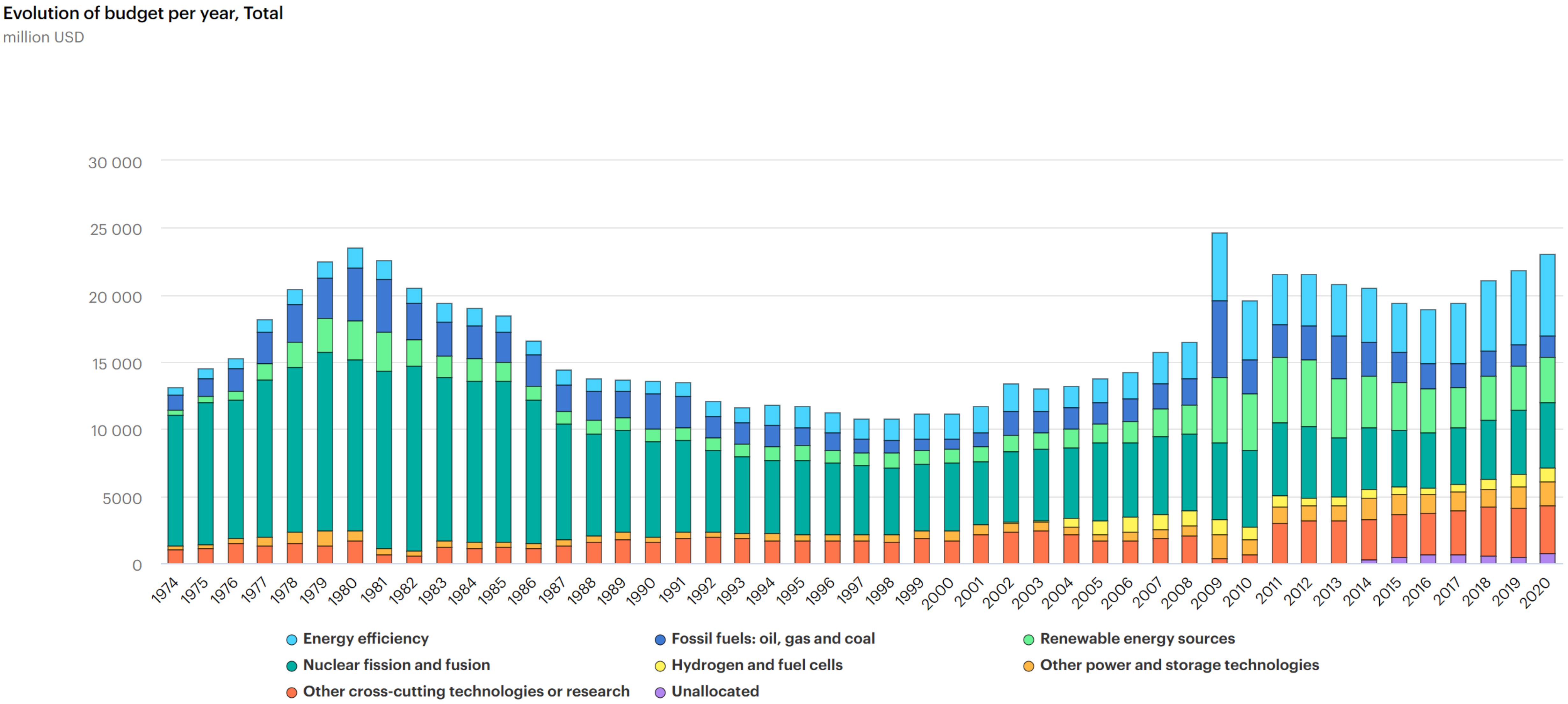
#UofGWorldChangers
@UofGlasgow

‘Zero’, ‘net-zero’ & ‘negative net-zero’



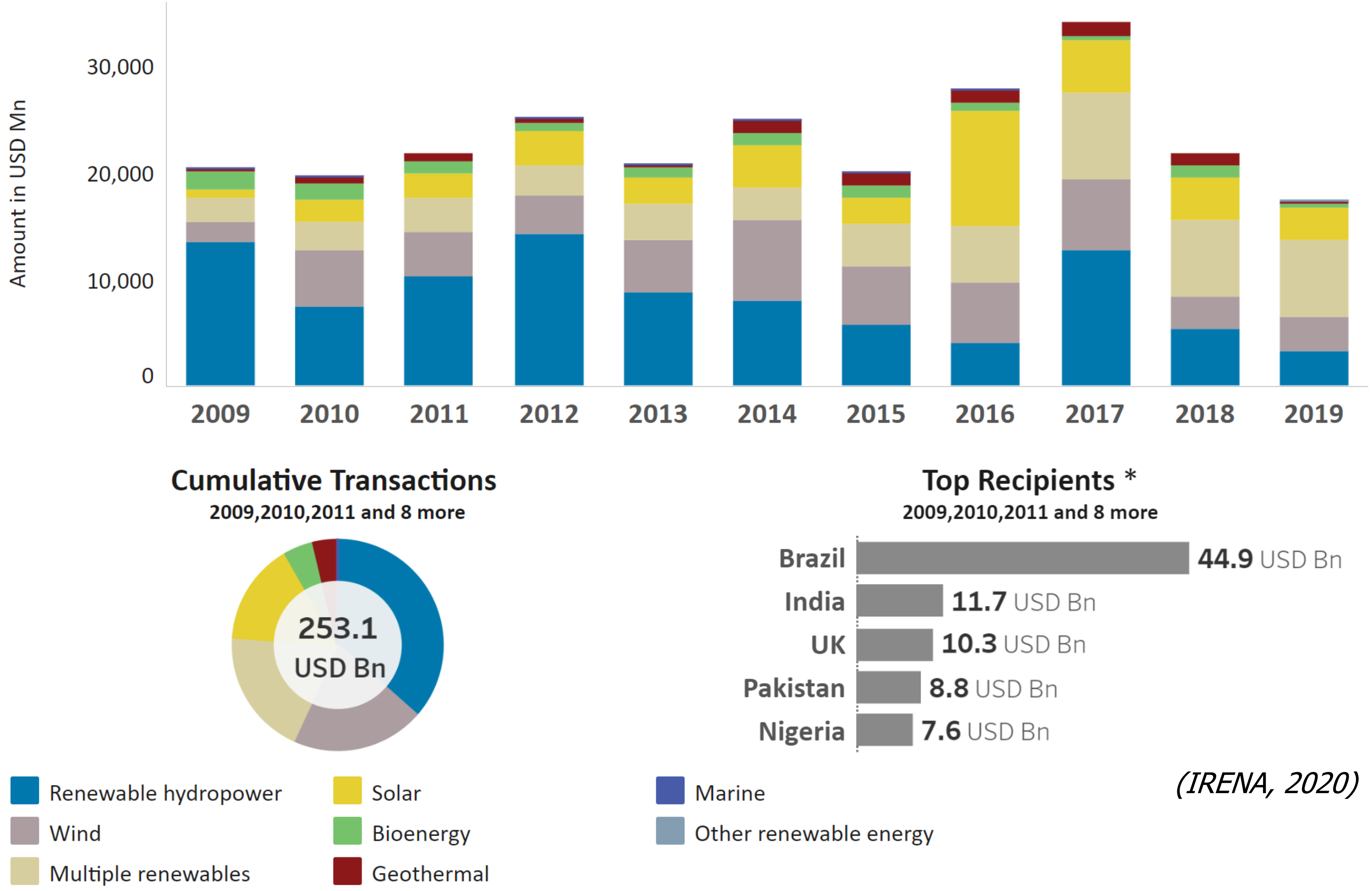
(Climate Analytics, 2019)

Evolution of total budget



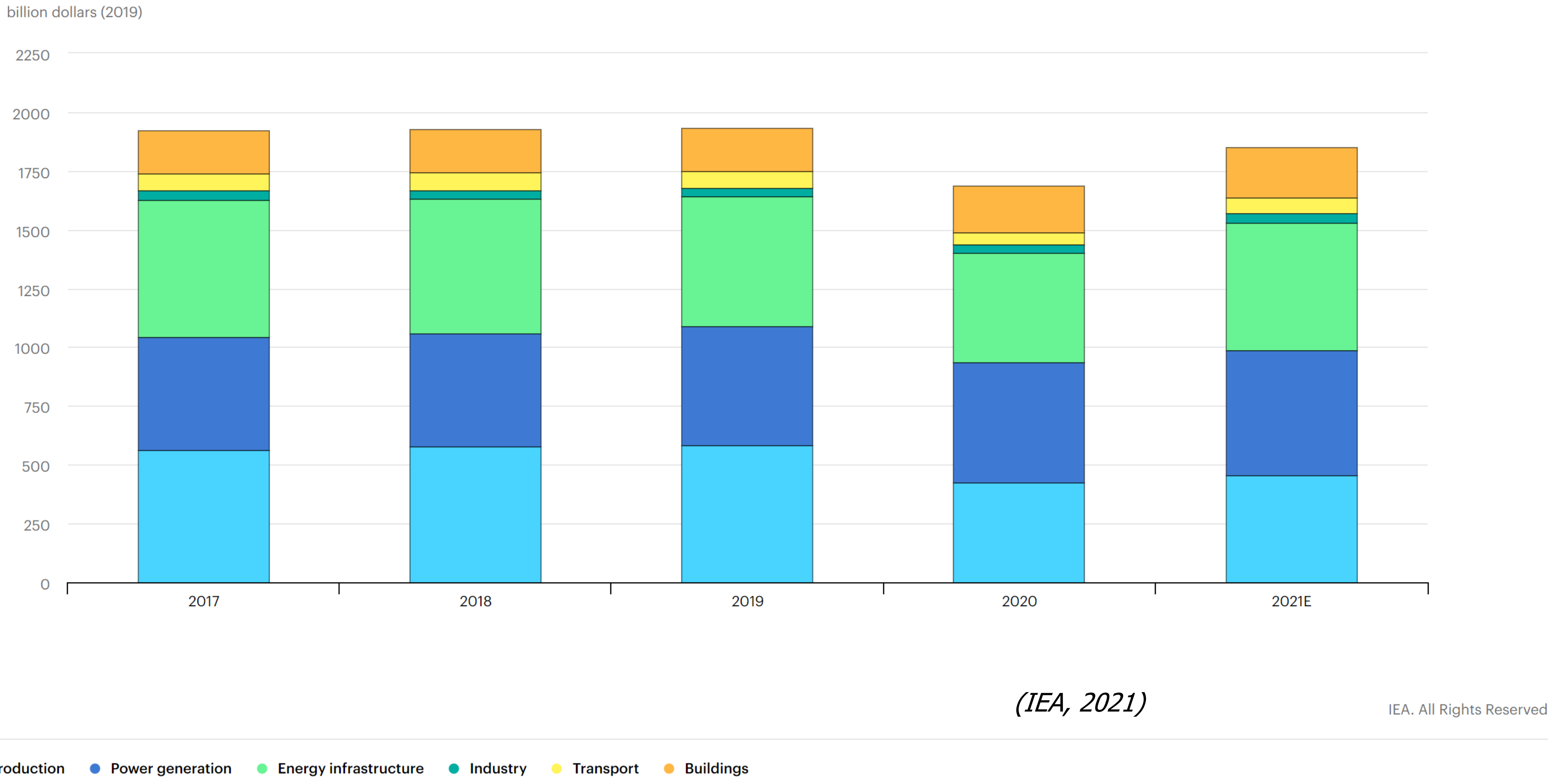
(IEA, 2021)

Public investment in renewables



(IRENA, 2020)

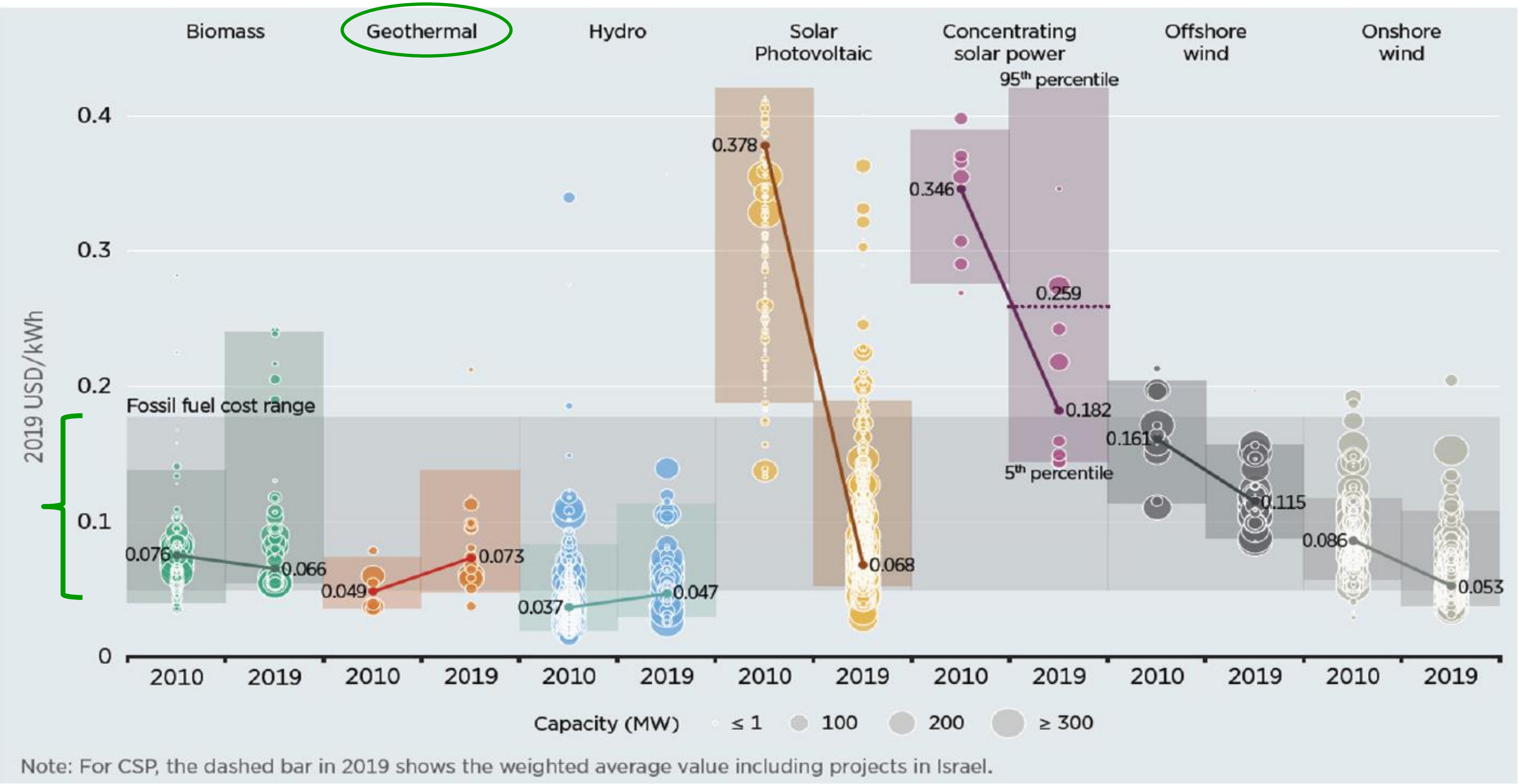
Global energy investment, 2017-2021



(IEA, 2021)

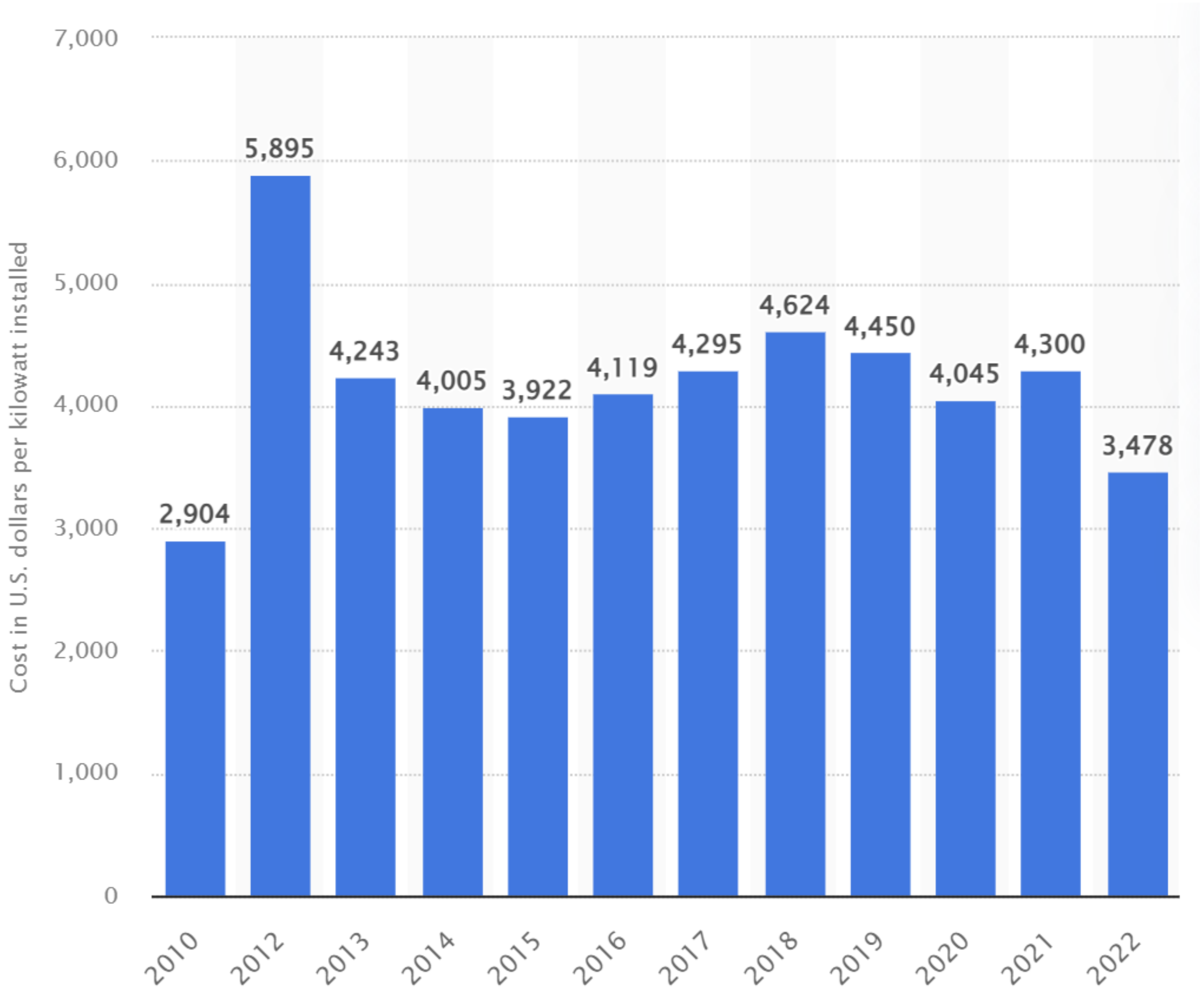
Global LCOEs from newly commissioned utility-scale renewable power generation technologies

(Different from LCOH)



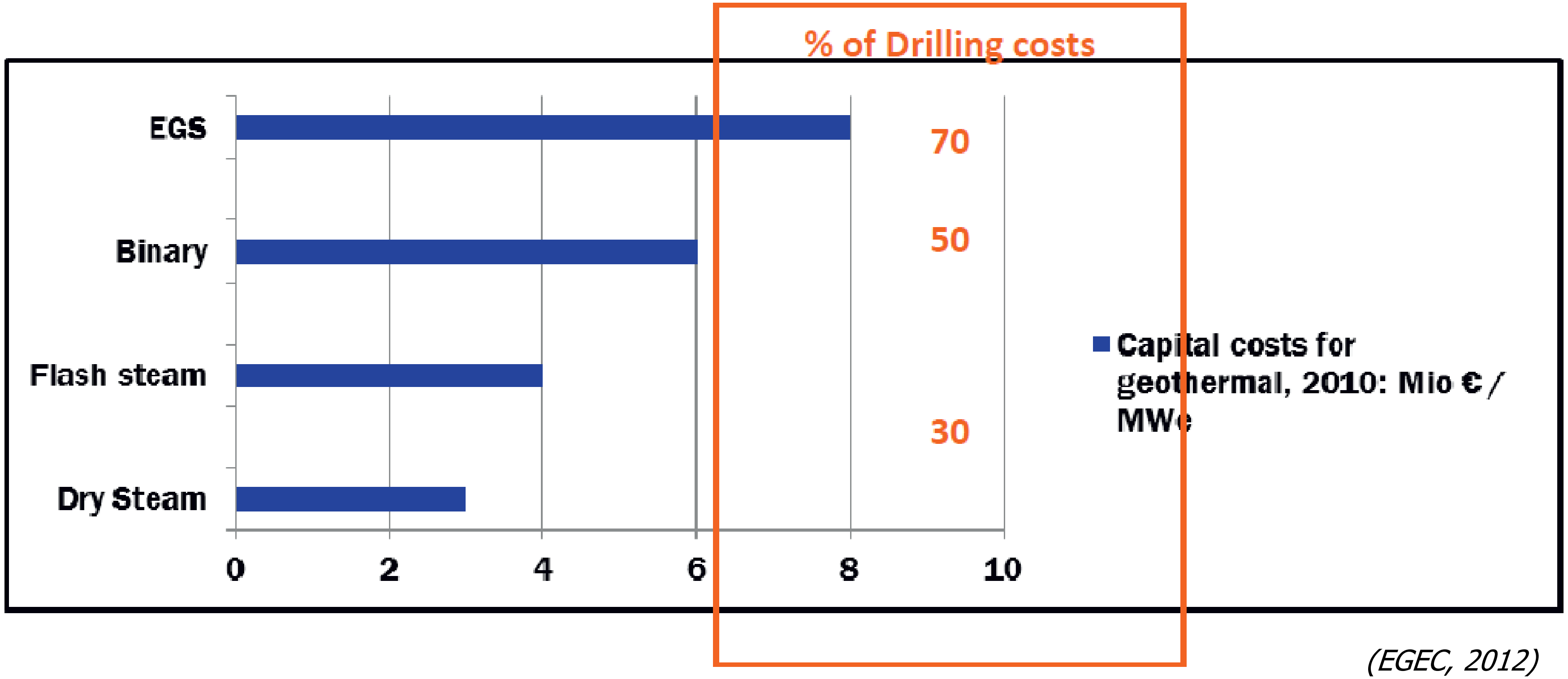
(EGEC, 2021)

Global geothermal power costs



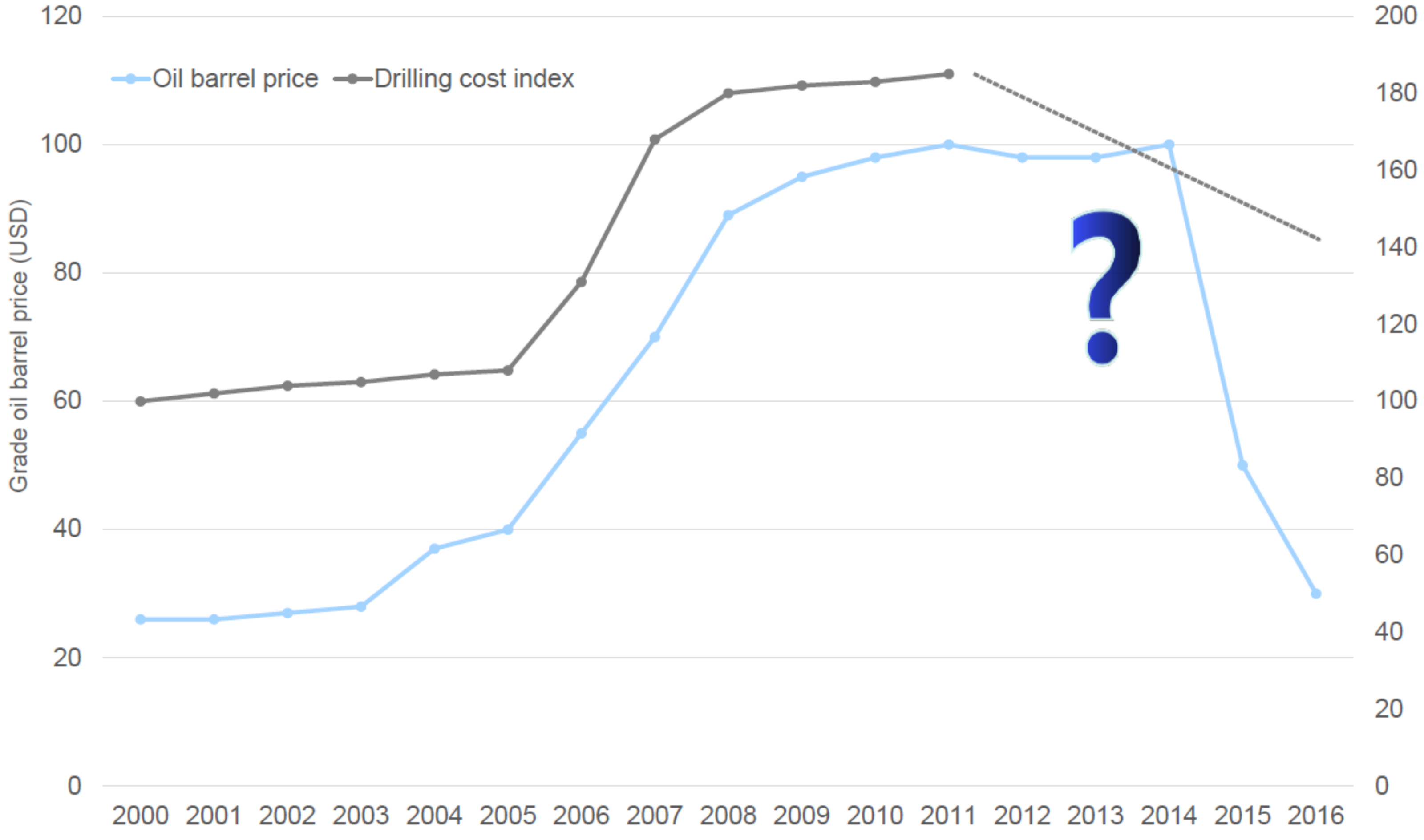
(Statista, 2024)

Drilling costs -1



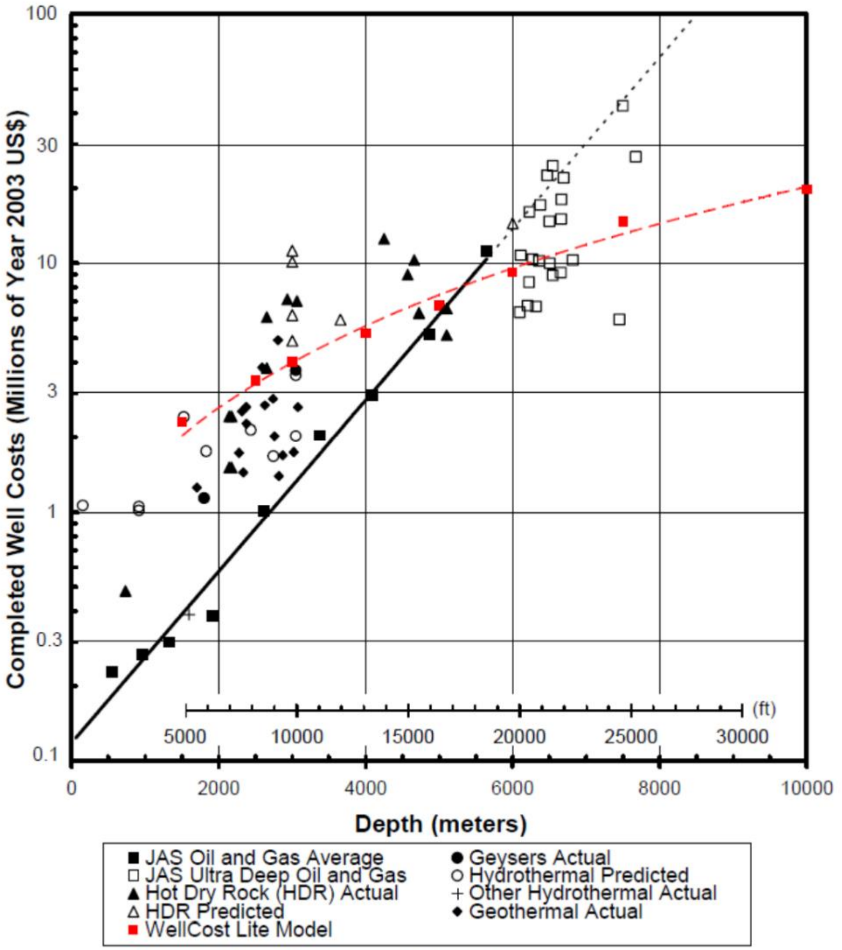
(EGEC, 2012)

Drilling costs -2



(EGEC, 2016)

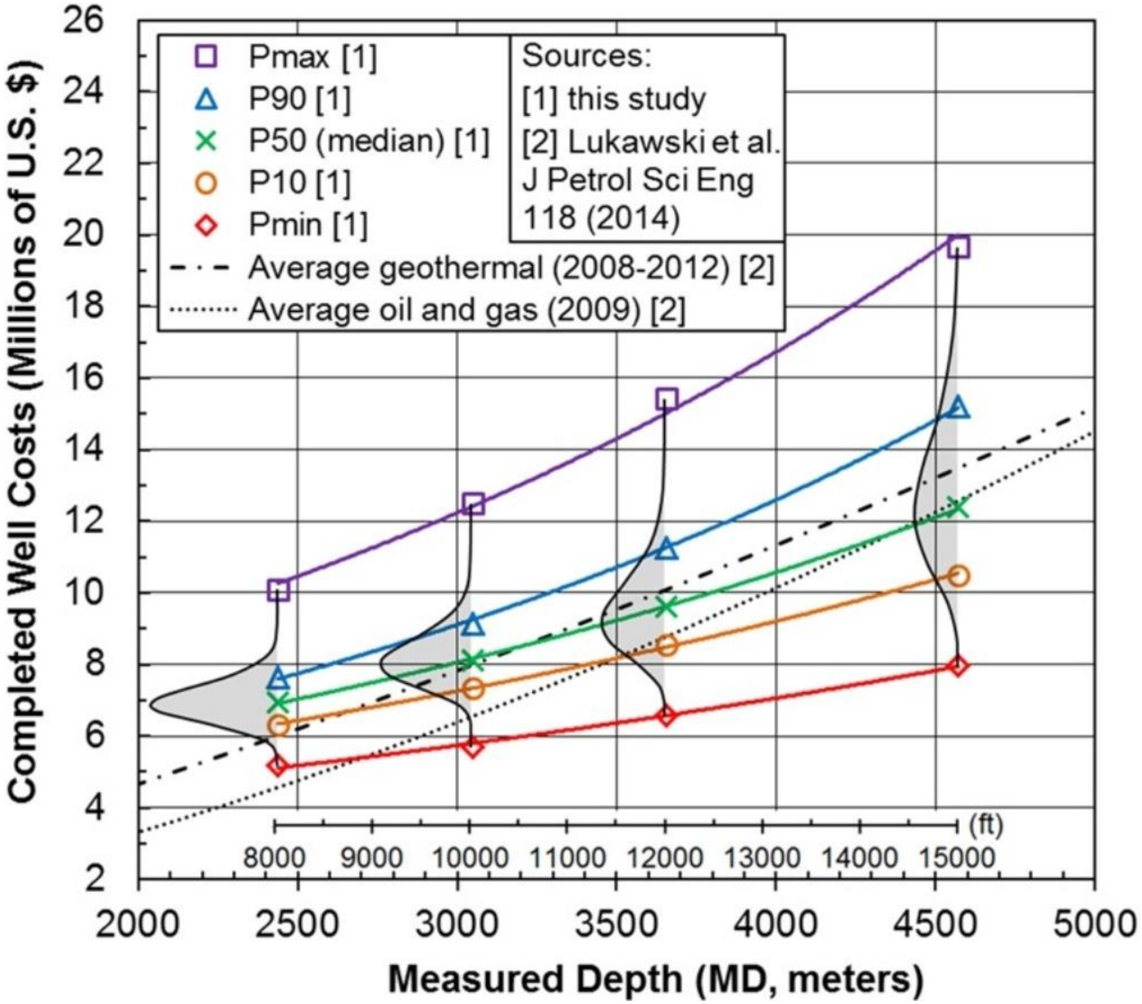
Oil&gas/geothermal wells costs -1



1. JAS = *Joint Association Survey on Drilling Costs*.
2. Well costs updated to US$ (yr. 2003) using index made from 3-year moving average for each depth interval listed in JAS (1976-2003) for onshore, completed US oil and gas wells. A 17% inflation rate was assumed for years pre-1976.
3. Ultra deep well data points for depth greater than 6 km are either individual wells or averages from a small number of wells listed in JAS (1994-2002).
4. "Geothermal Actual" data include some non-US wells (Mansure, 2004)

Completed well costs in year 2003 US $ as a function of depth (Augustine at al., 2006).

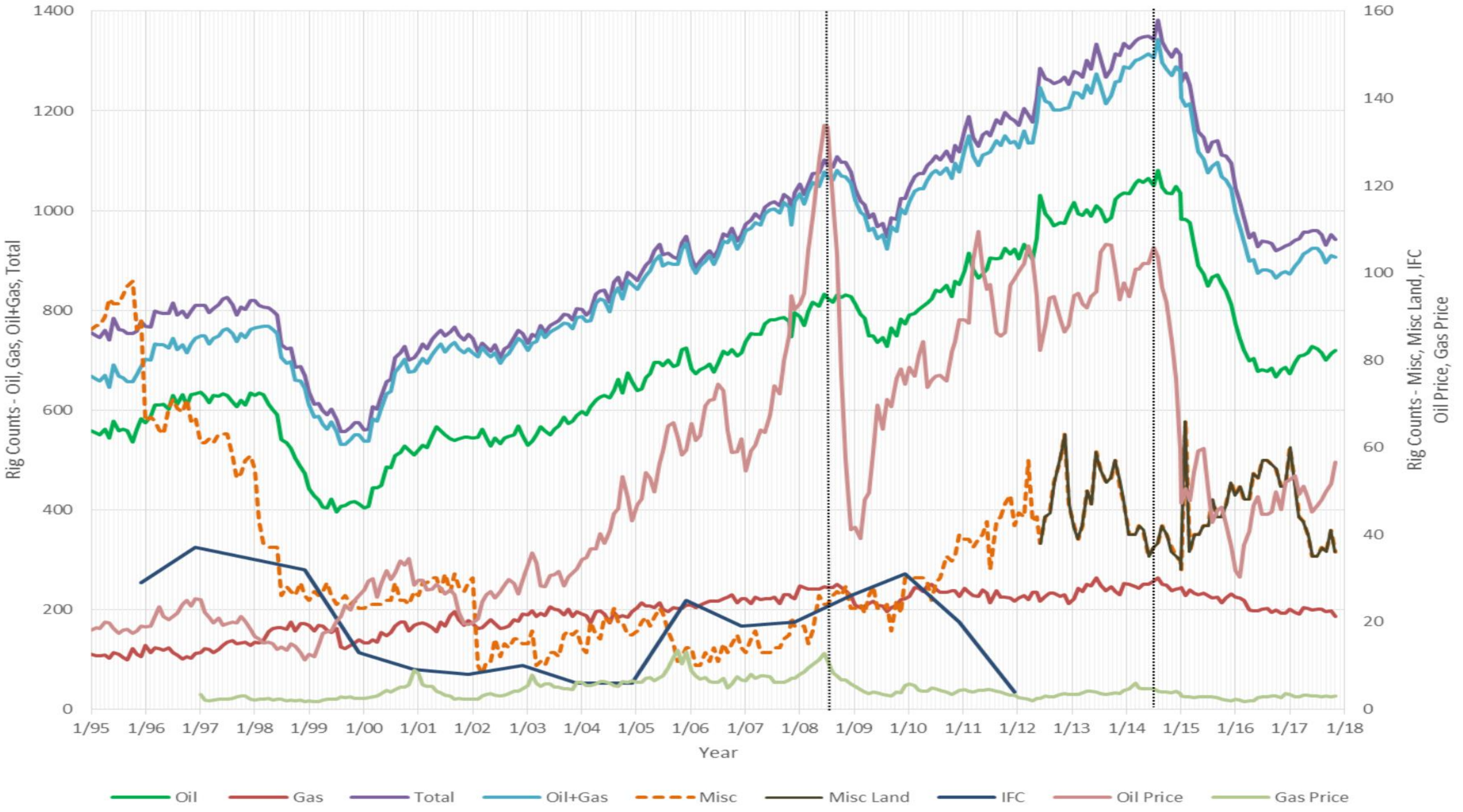
Oil&gas/geothermal wells costs -2



(Lukawski et al., 2016)

Drilling: lost windows of opportunity?

(Falcone and Teodoriu, 2018)



Baker Hughes rig counts vs. IFC geothermal well counts vs. oil and gas prices (up to and including December 2017). Oil price in USD per Barrel, gas price in USD per million Btu.

Global energy investment, 2017-2021