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Kiko Network Paper

Universal failure: How IGCC coal plants waste money and emissions

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Summary

- Integrated Gasification Combined Cycle (IGCC) coal plants are a dirty form of power production. Although IGCC is promoted as 'clean coal', it is many times more carbon-polluting than renewable alternatives like wind and solar.
- IGCC is expensive. The technology is about 35% more expensive than conventional coal technology. Adding carbon capture and storage (CCS) technology makes it even more expensive. Evidence from the USA suggests the electricity produced from IGCC plants with CCS will cost twice as much as electricity from wind or commercial scale solar plants.
- IGCC is not a new technology, and it is not a successful one. IGCC was first tested on coal power plants in the 1990s. Since then attempts to build IGCC coal power plants have met with delay, failure and significant cost overruns.
- IGCC has never reached critical mass. Just eight IGCC coal power plants are operating worldwide, according to publicly available data. Meanwhile, at least 18 planned projects have been cancelled, delayed or put on hold in the last five years.
- IGCC is a waste of money. As an example, at least $20 billion has been committed to IGCC projects in the USA in the last decade. The result so far is one power station struggling with technical problems, and one about to open after years of delays and cost overruns.
- The international community has pledged to limit global temperature rise to 2°C above pre-industrial levels and aim for a lower, 1.5°C limit. Building new coal power plants is incompatible with this goal, making IGCC an expensive technological dead-end, even if it can be made to work financially.

What is IGCC?

Coal generates 40% of the world's electricity.[1] But the industry has a problem - it also produces 42% of carbon dioxide emissions from the fossil fuel sector, making it the biggest single contributor to climate change.[2] In the Paris Climate Change Agreement in December 2015, the international community pledged to limit global temperatures to "well below" 2°C above pre-industrial levels and to "pursue efforts" to limit temperature rise to 1.5°C. It is impossible to do so if the world keeps burning coal at its current rate.[3]

The global coal industry is promoting so-called 'high efficiency, low emissions' (HELE) coal power stations as a solution. The World Coal Association (WCA) argues that HELE coal plants will allow governments to carry on exploiting coal and reducing emissions at the same time, because per unit of power generated HELE plants produce less emissions than conventional coal power stations.[4]

Integrated Gasification Combined Cycle (IGCC) is one form of HELE technology. In IGCC power plants, coal is gasified, creating a form of gas known as syngas. This is then used to power a turbine, creating electricity.[5]

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1 http://www.worldcoal.org/coal/uses-coal/coal-electricity

2 http://www.globalcarbonproject.org/carbonbudget/15/hl-compact.htm, http://www.wri.org/sites/default/files/pdf/global_coal_risk_assessment.pdf

3 http://www.nature.com/nature/journal/v517/n7533/full/nature14016.html, http://climateactiontracker.org/assets/publications/briefing_papers/CAT_Coal_Gap_Briefing_COP21.pdf

4 https://www.worldcoal.org/high-cost-divestment

5 Coal gasification can also be used to make chemicals for industry, or synthesise gas for burning directly. In other cases, oil can be gasified in an IGCC plant. This report focuses only on IGCC power plants which use coal as a feedstock, and use the gas to power a turbine.

IGCC is a more efficient way of generating power than burning the coal directly, and therefore less polluting.[6] A standard coal plant converts up to 38% of the coal's energy to power, according to international data.[7] IGCC technology can raise this figure to 45 - 50%.[8] Overall, IGCC plants emit around 20% less carbon dioxide than conventional coal plants, according to Japanese industry data.[9]

But IGCC has several disadvantages which have limited its take up. First, it is expensive. The US Energy Information Administration estimates that an IGCC coal plant costs around $4.4 billion per gigawatt of capacity to build, making it about 35% more costly than a conventional coal plant.[10]

Secondly, IGCC plants are complicated and difficult to build, and getting plants to operate successfully has not proven easy. As a result many new-build IGCC plants have experienced technical problems.[11]

Thirdly, even though IGCC coal plants are more efficient than conventional coal plants, they are still highly polluting. Conventional coal is about twice as carbon-polluting as gas power stations and at least ten times as polluting as renewable sources like wind and solar power.[12] Reducing coal's emissions by an additional 20% will have a limited impact on these figures.

IGCC and carbon emissions

New coal could single-handedly ruin our chances of meeting the 2°C target. 1,400 GW of new coal capacity is currently planned, permitted or under construction globally. If all of these plants are built it would be impossible to limit temperature rise to 2°C, even if all other emissions from generating electricity fell to zero.[13]

This is true even if all the new coal plants were all built to the highest HELE standards. In other words, even if every single planned coal power plant used IGCC technology, new coal would still tip the world into dangerous climate change.

Carbon capture and storage (CCS) technology could theoretically be used to reduce emissions further. IGCC plants are described as 'capture ready', because the technology makes it easier to attach CCS to an IGCC plant than a conventional power plant.[14]

If every new coal plant used both the most efficient HELE technology and CCS, global temperature rise could feasibly be limited to 2°C.[15] But this is a highly unlikely scenario. Attempts to develop IGCC/CCS plants in

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http://www.worldcoal.org/reducing-co2-emissions/gasification, http://www.netl.doe.gov/research/coal/energy-systems/gasification/gasifipedia/igcc

[6] https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapHighEfficiencyLowEmissionsCoalFiredPowerGeneration_WEB_Updated_March2013.pdf, https://www.mhi-global.com/discover/earth/technology/gtcc_igcc.html

[7] http://www.ecofys.com/files/files/ecofys-2016-incompatibility-of-hele-coal-w-2c-scenarios.pdf p.2

[8] http://www.ecofys.com/files/files/ecofys-2016-incompatibility-of-hele-coal-w-2c-scenarios.pdf, http://www.iea.org/media/etp/etp2012_tech_overview_01_coal.pdf

[9] http://www.bloomberg.com/news/articles/2015-07-29/japan-s-coal-hunger-poses-costly-challenge-to-emissions-icp9aioh, http://www.meti.go.jp/committee/kenkyukai/energy_environment/jisedai_karyoku/pdf/003_03_00.pdf, , http://www.hitachi.com/rev/pdf/2013/r2013_01_105.pdf

[10] 2013 figures http://www.eia.gov/forecasts/capitalcost/

[11] www.parliament.uk/briefing-papers/POST-PN-253.pdf

[12] Cited in http://www.ucsusa.org/clean_energy/our-energy-choices/renewable-energy/public-benefits-of-renewable.html#.V0WKOpMrLBJ

[13] http://www.ecofys.com/en/publications/the-incompatibility-of-hele-coal-technology-with-2c-scenarios/

[14] https://www.iea.org/publications/freepublications/publication/CO2_Capture_Ready_Plants.pdf

particular have proved to be very expensive projects, beset with difficulties. One recent assessment of the feasibility of a proposed IGCC/CCS plant in Australia concluded that "Industrial–scale, low emissions coal–fired power projects incorporating CCS are not currently economic'".[16] Evidence from the USA suggests that IGCC with CCS currently produces electricity at about twice the cost of onshore wind and utility scale solar power.[17]

IGCC: A stalled technology

IGCC isn't a new technology. It was developed in the 1960s and the first test coal plants using IGCC came online more than two decades ago, in the 1990s.[18]

Over the years, IGCC has been endorsed by a range of governments and commentators. It has been described as the "last chance for coal"[19] or "cleaner coal's last stand".[20] In the 2000's IGCC was supposed to provide a new wave of coal plants in the UK.[21] As recently as 2013, the US Energy Secretary said of IGCC coal plants: "We're going to need … maybe 100 more of these projects".[22]

Despite such enthusiasm, only a handful of IGCC plants have been built.[23] There are currently only eight active IGCC coal plants worldwide and one about the start commercial operation, according to data from Coalswarm, the US Department of Energy and other publicly available sources.[24] Three of those were constructed in the 1990s. Only five started operating in the last ten years - two in China, one in South Korea, one in the USA and one in Japan.[25]

The International Energy Agency (IEA) says "a large number of IGCC projects have been announced, offered for sale, then failed to proceed".[26] At least 18 planned IGCC plants have been cancelled, shelved or put on hold globally in the last five years alone, according to publicly available data.[27]

There are at least 20 projects in preparation or under construction around the world. In addition there may be about another ten being scoped in China, on which there is more limited data.[28] The financing for some of these projects is uncertain, however.[29] Globally nearly all IGCC projects "seem to have experienced varying degrees of cost overruns, delays and doubts about their viability".[30]

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15 http://www.ecofys.com/en/publications/the-incompatibility-of-hele-coal-technology-with-2c-scenarios/

16 http://www.uq.edu.au/energy/docs/ZeroGen.pdf

17 https://www.lazard.com/media/1777/levelized_cost_of_energy_-_version_80.pdf

18 http://www.worldcoal.org/moving-forward-huaneng-greengen-igcc-demonstration

19 http://www.power-technology.com/features/featureigcc-the-future-of-coal-power-4583854/

20 http://spectrum.ieee.org/energy/fossil-fuels/cleaner-coals-last-stand

21 See e.g. https://www.cps.org.uk/files/reports/original/111026192029-cleancoal.pdf, www.parliament.**uk**/briefing-papers/POST-PN-253.pdf

22 http://www.power-eng.com/blogs/power-points/2014/02/a_remarkable_proje.html

23 http://www.iea-coal.org.uk/documents/83195/8792/Recent-operating-experience-and-improvement-of-commercial-IGCC,-CCC/222

24 See separate spreadsheet. Sources include http://www.netl.doe.gov/research/coal/energy-systems/gasification/gasification-plant-databases/china-gasification-database

25 See separate spreadsheet

26 http://www.iea-coal.org.uk/documents/83195/8792/Recent-operating-experience-and-improvement-of-commercial-IGCC,-CCC/222

27 See separate spreadsheet

28 http://www.canon-igs.org/event/report/report_141115/141115_ryuu_presentation.pdf p.7

29 See for example http://www.sourcewatch.org/index.php/Galilee_Power_project, http://energy.gov/sites/prod/files/2016/04/f30/OIG-SR-16-02.pdf

30 http://www.powermag.com/does-igcc-have-a-future/?printmode=1

Case study: Spain

The Elcogás Puertollano plant in Spain opened in December 1997. The plant was intended to demonstrate the ability to convert poor quality coal with a high ash content into a less polluting power source.[31] At the time, newspaper articles labelled it a "technological bet for clean coal".[32]

At around 300MW, Elcogás was the largest IGCC plant in the world to use solid fuel, although still smaller than a typical 500MW coal plant.[33] The plant was part-funded by the European Commission.[34]

In its first ten years of operation, Elcogás experienced numerous technical difficulties and more than 6000 modifications were made to the plant's design.[35] By July 2014, it had accumulated 190 million Euros of debt, and its operators requested permission to close.[36]

A Spanish government rescue package - proposed on the basis that Elcogás was "environmentally beneficial" - was rejected by the European Commission. Independent assessors in Spain also ruled it anti-competitive. The plant closed for good on 31 January 2016, and the Spanish government does not appear to have plans to encourage any more IGCC coal plants.[37]

Case study: USA

Expectations for IGCC technology were higher in the USA than anywhere else in the world. Numerous IGCC coal power stations were proposed in the early 2000s, but most never passed the planning stages. Between 2007 and 2009 alone 14 IGCC projects in the USA were cancelled, according to Coalswarm data, including plants in Florida, Wyoming and Colorado.[38] Many were cancelled when a dramatic fall in gas prices as a result of the booming shale gas industry made expensive IGCC coal plants even less competitive.[39]

Today, there are only three IGCC plants operating in North America - one of which will shortly be converted to production of fertiliser rather than electricity.[40] The world's first commercial scale IGCC plant, in Indiana, started operating in June 2013. The company originally estimated that cost of the plant at around $2 billion. After cost overruns and delays, the cost rose to $3.5 billion. The plant attracted considerable local opposition, and has struggled with technical problems since opening.[41]

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[31] http://www.netl.doe.gov/research/coal/energy-systems/gasification/gasifipedia/elcogas

[32] http://elpais.com/diario/1996/05/29/sociedad/833320826_850215.html, http://elpais.com/diario/1996/05/29/sociedad/833320829_850215.html

[33] http://www.elcogas.es/en/igcc-technology/desing-technology

[34] http://www.elcogas.es/en/igcc-technology/further-developments/closed-projects

[35] https://www.usea.org/sites/default/files/082013_Recent%20operating%20experience%20and%20improvement%20of%20commercial%20IGCC_ccc222.pdf

[36] http://www.eldiario.es/clm/Elcogas-fracaso-apuesta-renovables_0_478053006.html

[37] https://www.boe.es/boe/dias/2015/09/18/pdfs/BOE-A-2015-10073.pdf, https://www.boe.es/boe/dias/2015/11/13/pdfs/BOE-A-2015-12279.pdf

[38] http://www.sourcewatch.org/index.php/Integrated_Gasification_Combined_Cycle_(IGCC) http://www.sourcewatch.org/index.php/Polk_Power_Station_Unit_6, http://www.sourcewatch.org/index.php/Buffalo_Energy_Project, http://www.sourcewatch.org/index.php/Bowie_IGCC_Power_Station

[39] http://www.iea-coal.org.uk/site/2010/news-section/news-items/southern-duke-push-us-coal-gasification-others-quit

[40] http://www.stamfordadvocate.com/business/article/Stamford-firm-to-convert-clean-coal-plant-7677695.php

[41] http://www.indystar.com/story/money/2015/06/13/problems-pile-edwardsport-power-plant/71042726/, http://www.powermag.com/edwardsport-igcc-project-start-marks-delayed-costly-milestone/, http://ieefa.org/dukes-edwardsport-igcc-still-dealing-with-technical-problems/, http://ieefa.org/edwardsport-future-coal-fired-power-not-bright-future/ , https://myweb.in.gov/IURC/eds/Modules/Ecms/Cases/Docketed_Cases/ViewDocument.aspx?DocID=0900b6318016d045

Kemper County, Southern Company's iconic 580MW plant in Mississippi, has not yet started operation. Proposed as the world's first large scale IGCC plant with carbon capture and storage (CCS), the cost of the plant was originally estimated at around $2.2 billion.[42] This then rose to an estimated $6.66 billion, making it one of the most expensive energy projects ever.[43] Earlier this year, Southern Company was accused of deliberately hiding the project's costs in order to protect its access to government subsidies.[44] The plant will now open at the end of November, according to reports[45] - three years behind its original schedule.[46]

Another project in Texas - the 'Texas Clean Energy Project' (TCEP) located near Odessa - also aims to combine IGCC with CCS technology. Originally planned for completion in June 2014, TCEP is currently still in the planning stages. The projected cost has doubled from about $1.9 billion to $3.9 billion. So far it has cost the US taxpayer $116 million, according to a recent report from the US Department of Energy.[47]

The complicated design of IGCC/CCS plants means these new-build plants have encountered a large number of technical problems, increasing their cost and leading to delays. In turn this has discouraged investors, making it more difficult to access financing.[48]

At least $20 billion of public and private sector money has been committed to IGCC power stations in the USA in the last decade.[49] To date this has produced one coal power station struggling with technical problems, and one about to open after years of delays and cost overruns.

Case study: China

China is the largest market for coal gasification technologies in the world. China uses coal gasification technology to make chemicals from coal; to generate substitute natural gas, and to generate liquid transport fuels. Despite gasification being a familiar technology, the government's investment in IGCC technology has been relatively limited. This is probably because it is an expensive way of generating electricity, compared to other methods.[50]

Publicly available data suggests there are currently two IGCC plants using coal to generate electricity in China. One is a 'polygeneration' plant, which use the coal gasification process to synthesise chemicals, and generate power as a minor part of its business.[51]

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[42] http://energy.gov/sites/prod/files/nepapub/nepa_documents/RedDont/EIS-0409-DEIS-01-2009.pdf, https://sequestration.mit.edu/tools/projects/kemper.html

[43] http://www.bloomberg.com/news/articles/2014-04-14/coal-s-best-hope-rising-with-costliest-u-s-power-plant, http://www.powermag.com/kemper-county-igcc-costs-rise-and-delays-loom-again/, http://d1lge852tjjqow.cloudfront.net/CIK-0000092122/abe60225-48c6-4c94-8a41-4cbc056c55bb.pdf

[44] http://www.nytimes.com/2016/07/05/science/kemper-coal-mississippi.html?_r=0

[45] http://www.powermag.com/delayed-again-kemper-county-igcc-plant-to-start-operations-in-a-month/

[46] http://www.powermag.com/kemper-county-igcc-costs-rise-and-delays-loom-again/

[47] http://energy.gov/sites/prod/files/2016/04/f30/OIG-SR-16-02.pdf

[48] http://www.powermag.com/does-igcc-have-a-future/

[49] Calculation sheet 3 on separate spreadsheet

[50] http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002001511

[51] Yankuang Cathay Coal Chemicals Company polygeneration demonstration plant https://www.wilsoncenter.org/sites/default/files/Feature%20Article%20Advancing%20Carbon%20Capture%20and%20Sequestration%20in%20China%20A%20Global%20Learning%20Laboratory.pdf p.110

A 250MW IGCC coal plant known as 'GreenGen I' is China's first full-scale IGCC power plant. Two planned extensions to the project would make the plant much larger, adding another 800MW of capacity as well as CCS technology to capture the carbon produced.[52] The first extension was originally planned for 2015, but according to press coverage has been delayed to 2020. Cost overruns are not publicly known.[53]

Local reports suggest there are about another 10 IGCC power projects being scoped out in China.[54] The Chinese government, however, has recently suspended construction of coal-fired power plants in fifteen regions and is curtailing coal plant approvals in others.[55] It seems questionable how many of these will actually be developed.

The future of IGCC

IGCC coal plants are not expected to form a major part of global growth in coal-fired plants over the next ten years. 'Supercritical' coal plants, which are cheaper than those using IGCC technology, accounted for 50-60% of so-called 'clean coal' installations from 2011 to 2014. In the future, the WCA expects supercritical coal - which are less efficient than IGCC plants - to continue to dominate.[56]

The WCA does argue, however, that IGCC will see "substantial additions" between 2015 and 2025, particularly in China and the USA.[57] Overall, the WCA sees Asia as the biggest market for clean coal - and many commentators see the success of planned IGCC plants in Asia as the "last chance" for the technology.[58]

South Korea aims to source 11% of total energy consumed from "new and renewable energy" by 2035. Under the terms of a 2014 Act IGCC counts towards this total, and IGCC receives government support alongside renewable energy like wind and solar power.[59]

In August 2016, South Korea started operating its first IGCC plant in Chungcheongnam-do, about 100 miles southwest of Seoul.[60] This was despite the fact in April 2015, the 'Board of Audit and Inspection' in South Korea published a warning concluding that the plant would not meet the expected efficiency or emissions reductions originally anticipated.[61]

Plans for at least two other IGCC plants are pressing ahead in South Korea. In December 2015, for example, an American and South Korean company announced their intention to investigate using IGCC technology at a new 1,000MW Saemangeum Industry & Research Area. If built, it would be the largest IGCC plant ever constructed.

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[52] http://www.worldcoal.org/moving-forward-huaneng-greengen-igcc-demonstration, http://www.iea-coal.org.uk/site/2010/blog-section/blog-posts/hele-workshop?

[53] http://www.powermag.com/does-igcc-have-a-future/?printmode=1

[54] http://www.canon-igs.org/event/report/report_141115/141115_ryuu_presentation.pdf

[55] http://energydesk.greenpeace.org/2016/04/13/china-continues-crackdown-new-coal-power-plants/, http://www.reuters.com/article/us-china-power-coal-idUSKCN0WQ0ZD

[56] http://www.worldcoal.com/special-reports/13072015/Cleaning-up-the-coal-power-market-2551/

[57] http://www.worldcoal.com/special-reports/13072015/Cleaning-up-the-coal-power-market-2551/

[58] http://www.powermag.com/does-igcc-have-a-future/?printmode=1

[59] http://english.motie.go.kr/?p=5444, http://www.innovasjonnorge.no/Documents/old/PageFiles/4014/Energy%20report%20NEA%20v3.pdf

[60] http://www.businesskorea.co.kr/english/news/industry/15621-commercial-operation-igcc-korea-western-power-begins-commercial-operation-taean, http://www.gasification-syngas.org/uploads/downloads/2015-presentations/2015-9-2-Seungmin-Doosan.pdf

[61] http://www.bai.go.kr/bai/groupreport/auditResults.do?mdex=bai225&rpstOrgCd=0000000340&audYr2=2014&audNo=137&dspRqSno=7&isSearch=1

The US-based partner, Southern Company, also owns Kemper County in the USA, and proposes to use the same technology in the new South Korean plant.[62]

Japan is the only country in the G7 group of industrialised nations planning to significantly increase its coal generating capacity.[63] Japan's 'strategic energy plan', adopted in 2014, suggests that coal will generate about a quarter of the nation's electricity by 2030.[64]

Japan has also committed to reducing greenhouse gas emissions by 26% by 2030, compared to 2013 levels. Climate thinktank Climate Action Tracker has judged this target as "inadequate", and consistent with an overall global temperature rise of 3-4°C.[65] Every one of Japan's 48 new coal power stations would have to be fitted with some kind of emissions-reducing technology for the country to hit its emissions reduction target, according to analysts.[66]

Japan's strategic energy plan promotes the use of "highly efficient coal thermal power generation" as a way of "reducing the environmental load" of new coal-fired power stations. Amongst other approaches, the government supports the use of IGCC technology.[67]

Japan currently has one medium scale IGCC plant operating and three under construction.[68] The Nakoso power station, 250MW, started full operation in April 2013, after a period of experimental operation from 2007-2012.[69]

Of the new projects, Osaki Coolgen was launched in 2009 and subsidized by the Japanese government.[70] The project was planned in three steps. The first step is the demonstration of the test facility for oxygen-blown IGCC. The second step is the demonstration of IGCC with CO2 capture equipment. The third step is the demonstration of IGCC with CO2- capture, combined with a fuel cell. The first step is nearly completed. The schedule for the second and third stage has not yet been announced.
The other two projects are new IGCC plants owned by Mitsubishi and Hitachi in Fukushima, aiming to start operation from 2020. Those are supported by the government as Fukushima Reconstruction projects. The IGCC plants will be capable of operating at 50% efficiency, according to data compiled by the Japanese government.[71]

The total cost for these projects are not publicly known, but an expert says the IGCC plant is 20% more costly than coal power plants. The high costs associated with IGCC, the problems experienced in constructing new plants and getting them operating, the early stage of commercial development compared to the long period that it has been available and the lack of evidence that costs will fall in the future, all suggest that IGCC plants are unlikely to deliver economic benefits.

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62 http://www.prnewswire.com/news-releases/south-korean-company-signs-first-letter-of-intent-to-explore-deployment-of-kemper-technology-300195757.html

63 https://www.e3g.org/docs/Japan_G7_Analysis_September_2015.pdf

64 http://www.enecho.meti.go.jp/en/category/others/basic_plan/pdf/4th_strategic_energy_plan.pdf

65 http://climateactiontracker.org/countries/japan.html

66 https://www.e3g.org/docs/Japan_G7_Analysis_September_2015.pdf

67 http://www.bloomberg.com/news/articles/2015-07-29/japan-s-coal-hunger-poses-costly-challenge-to-emissions-icp9aioh

68 http://sekitan.jp/plant-map/en/v2/table_en

69 http://www.joban-power.co.jp/nakoso_power_plant/igcc/

70 http://www.osaki-coolgen.jp/

71 http://www.bloomberg.com/news/articles/2015-07-29/japan-s-coal-hunger-poses-costly-challenge-to-emissions-icp9aioh

Building new coal plants also makes it more difficult to hit climate change targets - and opens utilities and companies up to the risk of creating assets that are not needed in the future. If global carbon budgets are tightened to reflect the 2°C target, Japan's plans for new coal plants risk creating $60 billion worth of stranded assets, according to an Oxford University study.[72]

In addition, the new plants may not be needed. Electricity demand in Japan fell for the fifth consecutive year in 2015, as a result of weak economic growth and energy efficiency measures.[73] Analysis by consultancy IEEFA suggests LNG and coal demand in Japan will decline by 2-3% annually from 2016 until 2020.[74]

IGCC coal power stations as stranded assets

The evidence cited in this report suggests that a major expansion of IGCC with CCS is highly unlikely. But any plants that get built without CCS will face an uncertain future. New coal power stations are built to last at least 25 years.[75] Avoiding a 2°C temperature rise means cutting electricity generation from coal power without CCS by 90% between 2015 and 2040, according to figures from the International Energy Agency.[76]

If the transition to a decarbonized economy gathers pace, or climate change targets are strengthened, such plants are at risk of having to be abandoned before the end of their operating life. Without CCS technology even 'efficient' coal plants risk becoming stranded assets[77]. IGCC plants with CCS would have lower emissions, but there is little evidence that IGCC with CCS is a success story waiting to happen.

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[72] http://www.smithschool.ox.ac.uk/research-programmes/stranded-assets/satc-japan.pdf
[73] http://ieefa.org/wp-content/uploads/2016/03/Japan-Energy-Brief.pdf
[74] http://ieefa.org/wp-content/uploads/2016/03/Japan-Energy-Brief.pdf
[75] http://www.iea-coal.org.uk/documents/81405/5990/Life-extension-of-coal-fired-power-plants
[76] Cited by consultancy Ecofys http://www.ecofys.com/files/files/ecofys-2016-incompatibility-of-hele-coal-w-2c-scenarios.pdf p.8
[77] http://www.carbontracker.org/report/unburnable-carbon-wasted-capital-and-stranded-assets/