**Introduction: CO2 Capture & Reuse and Hydrogen Research Trends**

- How To Transform Central Plants into Negative Carbon, Biofuel, Power & Storage Stations -

New chemistry now makes it profitable to upgrade and transform all central power plants that emit CO2 gas into Negative Carbon, Power & Storage Stations that remove CO2 from air in two stages. At the heart of this approach is a power plant or engine that runs on sustainable biofuel and ‘captures and reuses’ its own CO2 emission to make synthetic fuels and feedstocks. These proven methods, combined with recent legalization of industrial hemp and the refinement of many farm crops - kelp and algae too - opens the way to an agrarian revolution in energy markets.

The first stage (4-6 years) will reduce direct CO2 emission from a typical coal, gas or wood plant by up to 90%, not counting up-stream CO2. Many R&D groups now report specific catalysts that convert CO2 gas with H2O into H2 (for NH3) or methanol, ethanol or biodiesel in one step. Burning synfuel derived from CO2 in the same plant or engine the CO2 is from insures that up to 90% of direct CO2 emission is reused, kept out of air and accounted for. Plant operators can benefit from a) lower fuel cost, b) storage operations and c) Carbon Offsets (or subsidies) via Cap & Trade markets, as seen in the EU and widely anticipated in China, US and most nations. All sides of the political divide can join hands to capitalize on the profitable reuse of CO2 Emission *and* The Paris Climate Treaty.

The second stage (6-10 yrs) completes the conversion of a typical fossil plant into a ‘negative’ power & storage station by gradually replacing fossil fuels with farm fuels, i.e. methanol, biodiesel. Carbon forests need protection. Both H2 and other fuels can be made from CO2 and H2O *or* from hemp, pine, poplar, kelp, switchgrass, algae and other farm crops. As growing biomass removes CO2 from air, then a biofuel plant that reuses CO2 for extra fuel will actuate negative carbon emissions as defined by Klaus Lackner at The Center For Negative Carbon Emissions. Admittedly, the second stage is the greater challenge but consider: if some plants are carbon neutral and the rest carbon negative, then on balance the entire power system can become carbon negative within 10 years. Over that time, neutral plants can *gradually* convert to biofuels to actuate negative emissions on an industrial scale. A third stage of development can adjust negative plants to make fuels for vehicles and buildings. Imagine a ‘plug-in’ Prius that runs on NH3 (ammonia) or a biodiesel vehicle that reuses CO2 to make syndiesel for that same vehicle.

Optimal plant design should combine PV & batteries with biofuel generation & storage through the indispensible switching yard that all power plants include. Besides, utility storage is vital for grid security and to back up rapid growth of intermittent wind & PV. Vermont’s wood plants and VT Yankee are ideal candidates for this approach.

The IPCC and GND say we need to 'reduce' CO2 emissions and 'remove' CO2 from air and, in order to do this, we need to make ‘massive infrastructure changes within 10 years’. Sierra's solution, like many Progressive groups, is to actively close down coal plants and replace them with distributed renewables and storage. They advocate by varying degrees a Carbon Tax or Cap & Trade. They support greater efficiency and terrestrial sequestration, i.e. nurturing forests, planting trees and sustainable farming with biochar sequestration to remove CO2 from the air. These combined measures are all well and good with no better choice. Unfortunately, we have waited too long to put them to work. By themselves, they will not work fast enough to prevent a run-away greenhouse effect. As Bill McKibben has said, “If we are winning slowly, then we are still losing.” Yet, these combined measures will work very well and quickly too if only we also transform central plants - instead of closing them down - thereby making them carbon neutral and then carbon negative. Tail pipes and building flues can be treated in a similar fashion.

The missing ingredient in climate prescriptions from Progressives, Democrats, enlightened Republicans and Environmentalists in general is a fast, direct and profitable way to 'remove' CO2 from air - one that can be installed within 10 years or less. Unfortunately, companies like Carbon Engineering have the right chemistry but the wrong application. So-called, 'direct air capture' is inherently unrealistic in its present form. Meanwhile, despite closures and declining orders, the total number of power plants in the world is going up. The great majority of existing plants will persist for well over 20 years. Closing them down en mass in 10 or even 20 years is unlikely despite Sierra's noble efforts. Yet, Sierra’s climate blueprint does not include the profitable conversion of fossil plants from massive CO2 emitters into major CO2 removers. So plants and jobs will close and local economies suffer too?

Still the best way to remove CO2 from air is Mother Earth's - growing living vegetation. Accordingly, farm biofuels can gradually replace fossil fuels over 6-10 years if it's lucrative to do so. In this way, CO2 emission from biofuel power plants can be continuously reused to make supplemental fuel for the same furnace or engine that the CO2 is from, thereby reducing and removing CO2 emissions simultaneously and justifying Carbon Offsets and/or RECs. We can power and drive our way to healthy climate and lives if only we follow the science, as Dr. Fauci has said.

By Jim Hurt, Board Member, Renewable Nations Institute / for more information: hurtjim@gmail.com

**CO2 Capture & Reuse and Hydrogen Research Trends**

- How To Transform Central Power Plants into Negative Carbon, Biofuel, Power & Storage Stations -

Here is a list and brief review of recent lab reports on new ways to capture and reuse CO2 with water to produce; a) hydrogen, b) ammonia, c) methane, d) methanol, e) biodiesel, f) carbon nanotubes (CNTs) and g) carbonates to make many products. These reports confirm it is now profitable to upgrade and transform all central plants that emit CO2 into dual, power & storage stations that ‘remove’ CO2 from air. Central plants can evolve in two stages from dire climate threats into negative carbon factories that make clean watts, alternate fuels and more. New jobs, new fuels and carbon offsets or RECs this way will come. Besides, central storage is vital for grid security and to back-up rapid growth of intermittent renewables and electric cars. CO2 Reuse enhances the value of replacing fossil fuels with biofuels from hemp, pine, poplar and other sustainably cultivated, farm crops. Carbon forests need protection. Biofuels offer a far better climate/energy choice. The same methods can be applied to tail pipes and building flues.

The future belongs to distributed renewables, we may hope. By this view central power & storage can logically back up the rapid growth of Decentralized Energy Alternatives (DEAs). Renewables are clean but intermittent. Central power is steady but polluting. Yet the two can evolve together to actuate the optimal climate solution. Meanwhile, existing plants, especially coal plants, pose an imminent hazard to earth’s climate. A World Bank study reports: “The energy sector (watts & heat) contributes about 40% of global CO2 emissions per year. Three quarters of those emissions come from six major economies. Although coal-fired plants account for just 40% of world energy production, they are responsible for over 70% of energy-sector emissions in 2010. Despite improvements in some countries, global CO2 emission factor for energy generation has hardly changed over 20 years.”

See: Understanding CO2 Emissions From The Global Energy Sector, ’14, Foster & Bedrosyn, WBG website.

See: Decentralized Energy Alternatives, Columbia U. 1999; <https://archive.org/details/decentralizedene00dece>

Governments and utilities are not sufficiently incentivized to close down all the world’s 60,000+ power plants any time soon. Closing coal plants is fully justified with no better choice but will only put a dent in our CO2 crisis. Most plants today will run for *well over* 20 years due to vested interests, bad habits and entrenched antique technology. Yet, the IPCC & GND say we have only 9-10 years to make ‘unprecedented changes’ to reduce CO2 emission *and* remove CO2 from air, just to keep global warming to ‘moderate levels’. Worse, despite closures and a decline in new orders in some industrialized countries, still, many hundreds more coal plants are being planned or built in China, India, Japan and other nations. Thousands more gas plants are in the pipeline. These new plants alone will negate CO2 reductions we earthlings might otherwise make for the foreseeable future. In short, we can’t live without them, nor get rid of them fast enough. The better choice is to turn CO2 emitters into CO2 removers that make and store clean watts, H2, NH3, methane, methanol, ethanol and more. Transformation must be profitable or will not happen. Carbon pricing or something like it is key to spur new technology, which is now here.

See: <https://www.nytimes.com/2017/07/01/climate/china-energy-companies-coal-plants-climate-change.html>

Much early work in the ‘CO2 Capture’ field was pioneered by Klaus Lackner, still at ASU’s Center for Negative Carbon Emissions ([cnce.engineering.asu.edu](https://cnce.engineering.asu.edu)) as well as multiple programs at Columbia University. They support **a)** Direct Air Capture (DAC) of CO2 for geologic sequestration and **b)** carbon capture & storage (CCS) for power plants, and, the main focus of this paper, **c)** harvesting CO2 from central plants for reuse to make synfuels or other products. DAC is presently more costly then reusing CO2 from power plants. CO2 is only .04% of ambient air but over 10% of plant exhaust. Even so, Lackner says DAC is ultimately more necessary to cure our CO2 ills. Others say we should focus on power plants first and DAC later as it matures, as do I. The Center for Carbon Removal largely agrees with Lackner while seeking more rewarding carbon solutions. The debate is far from over.

See: [www.centerforcarbonremoval.org/](http://www.centerforcarbonremoval.org/).

A well-noted article, **Going Negative**, by Elizabeth Kolbert, New Yorker, 11/20/17, offers a concise over-view of CCS debate. Geologic sequestration of CO2 from the open air, DAC, is presented grimly as a tough love measure of last resort that offers 0 profit but can minimize or reduce atmospheric CO2, hence the term ‘negative’, meant as positive for climate. Both sequestration and CCS require pumping huge amounts of CO2 under great pressure deep into Mother Earth. Worries about earthquakes and water quality abound. A better version of CCS is BECCS (or Bio-energy Carbon Capture & Storage). BECCS calls for biofuels or biomassthat absorb CO2 from air. When burned, CO2 is pumped below to keep it ‘negative’. Sadly, after forty years of utility stalling, Lackner has less hope for CO2 Reuse for central plants, which he sees as carbon neutral at best or green washing fossil fuels at worst. Thus, DAC has become a much preferred path to negative carbon emissions to avoid utility and fossil opponents.

**Third Way: Solar/Wind/Biofuels with CO2 Reuse and Power Storage**

Other scientists want to take CO2 Reuse ‘negative’ via intensive CO2 recycling to aid Terrestrial Sequestration. These scientists say a neutral carbon plan is too slow. They seek a *fast and profitable,* negative carbon solution. One branch of this work is bio-energy carbon capture & reuse (BECCR) for central plants. One variant of this idea, presented here, accepts fossil fuels for now while preparing to replace them with sustainable biofuels from farms.

The first stage (4-6 years) will make a typical coal, gas or wood plant carbon neutral by up to 90%, not counting up-stream CO2. Many R&D groups now report new catalysts that convert CO2 gas with H2O into H2 (for NH3) or methanol, ethanol or biodiesel in one step. Burning fuel derived from CO2 in the same plant or engine that the CO2 is from insures that up to 90% of direct CO2 emission is captured, reused, kept out of air and accounted for. Plant owners can benefit nicely from a) lower fuel cost, b) storage operations and c) ample RECs or carbon offsets from Cap & Trade markets, as seen in the EU and widely anticipated in China, the US and most nations.

The second stage (6-10 years) will make a typical fossil plant ‘carbon negative’ by gradually replacing fossil fuels with sustainable biofuels, i.e. methanol or biodiesel *primarily from farms,* as old growth carbon forests deserve protection. H2 and biofuels can be made from CO2 and H2O *or* from hemp, pine, poplar, kelp, switchgrass, algae and other farm crops. As growing biomass removes CO2 from air, then a biofuel power plant that reuses CO2 for extra fuel will activate negative emissions as defined by Klaus Lackner at The Center For Negative Carbon Emissions. Again, the second stage is the greater challenge but consider: If most plants are carbon neutral and the rest carbon negative, then the entire power system can become net negative on the whole within 10 years. Over that time, neutral plants can *gradually* convert to farm biofuels to actuate negative emissions on an industrial scale.

For the record, not all biomass is equal with respect to sustainability or CO2. Monoculture palm oil, corn ethanol and wood chips from clear cutting entire forests are the worst offenders now. Hemp and many crops can be cultivated sustainably if machinery is electrified to cut upstream CO2 and cost. In time, flood-prone areas can be tapped to irrigate deserts for food and fuel crops and to cool climate as well. Over its lifetime, the power station described above will remove far more CO2 than emitted to build and run it. Tailpipes can be treated in same way.

A third stage of conversion can adapt negative emission power plants to produce alternate transportation synfuels. CO2 can be recycled as CO via the ‘water-gas-shift’ method (p.3) to make H2 for NH3 or methane, methanol, ethanol or biodiesel. CO2 Reuse can enable zero or negative emission vehicles. Imagine a ‘plug in’ Prius that runs on NH3 or a biodiesel vehicle that reuses CO2 to make syndiesel for that same vehicle. **(2)**

CO2 can also be stored in soils via biochar or mineralized into limestone, baking soda, and calcium carbonate thru ocean liming. All this assumes earth’s plant life will gradually remove CO2 from air if only earthlings stop adding more and even reduce it themselves. Unfortunately, that might take too long. Therefore, CO2 sequestration and CCS still hang heavily over the entire discussion as a last resort. Yet, CO2 Reuse is fast becoming commercially viable. It offers a way forward with further development and carbon pricing, offsets or RECs. Coal, gas, oil and defunct nuclear plants, like Vermont Yankee, can be transformed thru CO2 Reuse & H2 formation methodologies.

**Storage:** CO2 Reuse and H2 production via water have arrived just in time to meet rising demand for utility-scale, energy storage. New types of batteries and PV are here too. Taken together, these advances offer the real prospect of transforming central plants that emit CO2 into combined generation & storage stations that remove CO2 from air. Many proven technologies such as PV, wind, solar thermal, batteries, flywheels and pumped hydro can work very effectively and harmoniously with new CO2 & H2 production and storage mechanisms. Taken together, these old and new components can form a highly reliable, utility-scale, combined generation & storage approach. Power projects that combine these functions within one system can demonstrate and activate a new energy transformation paradigm: to harvest CO2 gas from central plants to make and store watts, H2, alternate synfuels and feedstocks. The latter can yield new kinds of plastic, cement and numerous saleable products. Coal, gas, oil and antiquated, dangerous, nuclear plants can now be repurposed along these lines, just in time, as China embraces carbon pricing.

Overall, the CO2 Reuse proposition for central plants directly answers the recent 2018 IPCC Report, calling for ‘removal of CO2’ from the atmosphere and ‘not just a reduction of future emissions’. The National Academies of Sciences agrees with the IPCC. The IEA Annual Energy Outlook ***and*** the Trump Administration’s very own National Climate Assessment concur as well. Ideally, removal and reduction should come together or we are digging a hole in the sky and filling it again. Therefore, *both* CO2 Reuse for central plants *and* Direct Air Capture (DAC) - when practical - are needed to ensure fast removal of CO2 from air in time to save us.

**Vermont Yankee** (VY) is one logical site for a biofuel power & storage station, designed to capture & reuse CO2 with water to make hydrogen or biofuels or feedstocks, including biochar for farms. These supplemental fuels can be **a)** stored and used on-site to reduce primary fuel usage or **b**) increase MW output to suit ‘peak load’ or **c**) sold for transport or heating fuel. Utility-scale, PV & Batteries can further enhance plant reliability. In theory, storage and gasification are consistent with VPIRG and VTDPS perspectives. On climate, it is better to burn ‘biogenic’ fuel than ‘geologic’ gas. Besides, VY has no gas pipeline. Hemp fuels from farms can replace wood chips from forests. Vermont Green is Vermont Strong for Vermont’s Economy, it may be said. Growing hemp for biofuel is cheap. Corn is costly. Palm oil is backward. Algae is tentative. Yet, Utah U. reports a major advance in Algae processing.

**Green The Deserts / Cool The Planet / Employ All Kinds of Americans**

One complaint against biofuel is competition with food production for fertile land. Yet, if an oil pipeline can be built from Canada to Texas, then new waterways can be built from flood prone areas in the Mid-West to Western & South-Western deserts. Greening deserts via pipelines, canals and aqueducts for large-scale irrigation projects powered by PV with drip-irrigation will provide vast new arable lands for both food and energy crops. Advanced desalination invites tapping seawater. CO2 gas can also be reused to make Roman-style concrete that hardens over centuries, evidenced by ancient aqueducts. Moreover, greening up to 20% of desert lands will cool our climate significantly. Black jobs matter. Immigrants need work. Poor whites are struggling to make ends meet.

**The Cheapest Way to Save the Planet Grows Like a Weed**, By Ellen Brown, The Web of Debt Blog, 07/30/19

From: <https://truthout.org/articles/the-cheapest-way-to-save-the-planet-grows-like-a-weed/>

# Making Environmentally Friendly Fuel From Industrial Hemp, by [NHA](https://nationalhempassociation.org/author/management/), 04/06/16

From: <https://nationalhempassociation.org/making-fuel-from-industrial-hemp/>

**Hemp to Potentially Replace Reliance on Fossil Fuels**, 04/18/11, by [Kevin McCarty](http://dailynexus.com/author/kevin-w-mccarty/), Daily Nexus

From: <http://dailynexus.com/2011-04-18/hemp-potentially-replace-reliance-fossil-fuels/>

**Hemp as a Fuel / Energy Source**, by Jeremy Briggs, Hemphasis; <http://www.hemphasis.net/Fuel-Energy/fuel.htm>

Related Study**:** Carbon Abatement, Gasification, Bioenergy & Biochar, 2016, UC Davis, By Pereira, Suddick & Six

Turning Algae into Fuel, Utah U reports advance: [www.eurekalert.org/pub\_releases/2019-03/uou-tai022819.php](http://www.eurekalert.org/pub_releases/2019-03/uou-tai022819.php)

**CO2 Capture – Recent Advances (3)**

The main focus of this paper is on CO2 Reuse Chemistry and how best to apply it to central power plants with appropriate biofuels derived from hemp and other sustainably cultivated crops. However, CO2 Reuse first requires capturing CO2 from a waste stream or ambient air. Here listed below is a small sample of better ways to do that over and above conventional CO2 scrubbing methods. See: Robert Service, St. Mary’s, Carbon Clean, C-Capture, Carbon Engineering and Lackner/Chen studies. Some make baking soda or methanol. An addendum is available.

# New generation CO2 traps could make carbon capture practical, By Robert Service, 3/24/21 Science, AAAS

<https://www.sciencemag.org/news/2021/03/new-generation-carbon-dioxide-traps-could-make-carbon-capture-practical> Excerpt: PNNL researchers are developing a new generation of chemical CO2 traps, reducing cost by nearly 20%.”

**Cheaper Carbon Capture Is On The Way – Marathon Research Effort Drives Down Cost** -

**PNNL-developed solvent breaks barriers, captures carbon for less than industrial counterparts.**

By PACIFIC NORTHWEST NATIONAL LABORATORY, MARCH 19, 2021, SciTechDaily

From: <https://scitechdaily.com/cheaper-carbon-capture-is-on-the-way-marathon-research-effort-drives-down-cost/>

Excerpt: Yuan Jiang says EEMP can absorb CO2 from flue gas and release it as pure CO2 for as little as $47.10/MT.

# Anion-activated, thermoreversible gelation system to capture, release & visually monitor CO2

# by [Xin Zhang](https://www.nature.com/articles/srep04593#auth-1), [Songyi Lee](https://www.nature.com/articles/srep04593#auth-2), [Yifan Liu](https://www.nature.com/articles/srep04593#auth-3), [Minji Lee](https://www.nature.com/articles/srep04593#auth-4), [Jun Yin](https://www.nature.com/articles/srep04593#auth-5), [Jonathan L. Sessler](https://www.nature.com/articles/srep04593#auth-6) and [Juyoung Yoon](https://www.nature.com/articles/srep04593#auth-7)

Scientific Reports volume 4, Article number: 4593 (2014) / From: <https://www.nature.com/articles/srep04593>

**Other Important CO2 Capture Developments:**

<https://asunow.asu.edu/20160721-asu-researchers-aim-pull-fuels-out-thin-air> (Klaus Lackner’s Center)

[www.newswise.com/articles/columbia-engineers-develop-new-low-cost-way-to-capture-carbon](http://www.newswise.com/articles/columbia-engineers-develop-new-low-cost-way-to-capture-carbon) (Lackner & Chen)

<http://springboardatlantic.ca/news/story/taming-a-poison-smu-researcher-discovers-plant-saving-ion> (St. Mary’s)

[www.chemistryworld.com/news/isolation-of-cyanoformate-suggests-new-carbon-capture-approaches/7245.article](http://www.chemistryworld.com/news/isolation-of-cyanoformate-suggests-new-carbon-capture-approaches/7245.article)

<https://carboncleansolutions.com/> (commercial now)

[www.theguardian.com/environment/2017/jan/03/indian-firm-carbon-capture-breakthrough-carbonclean](http://www.theguardian.com/environment/2017/jan/03/indian-firm-carbon-capture-breakthrough-carbonclean)

<https://www.c-capture.co.uk/> (Drax Power Plant approach, Great Britain)

<https://phys.org/news/2017-01-crystallization-method-option-carbon-capture.html>

**H2 Fuel, Bridge Fuels & Feedstocks from CO2/CO Conversion & Reuse**

**1) Two for Price of One: Water and Carbon Dioxide Splitting via a Single Catalyst,**

EFRC, North Carolina U, 12/01/12: “Researchers have discovered a metal complex that catalyzes two reactions, splitting water into H2 & oxygen and reducing CO2 to carbon monoxide in an electrochemical cell for splitting CO2 into carbon monoxide & oxygen.” From: <https://science.energy.gov/bes/highlights/2012/bes-2012-12-b/>

**2)** **Lights! Action! Photo-Activated Catalyst Grabs CO2 to Make Ingredients for Fuel**

By Sarah Yang, LBNL News center, 07/28/17 - Lawrence Berkley and Nanning Technological University (NTU) in Singapore collaborated to develop a new catalyst; “When exposed to visible light, the material, a ‘spongy’ nickel organic crystalline structure, converted CO2 exclusively into carbon monoxide gas.”

From: <http://newscenter.lbl.gov/2017/07/28/photocatalyst-grabs-co2-to-make-ingredients-for-fuel/>

**3) New efficient, low-temperature catalyst for hydrogen production** – ‘Low-temp, water gas shift' reaction produces high levels of pure hydrogen”, 06/22/17 – Brookhaven, Peking, DOE, Dalian & others, have developed a catalyst of gold Nano particles on a molybdenum-carbide substrate converting CO + H20 + watts into **H2** & CO2. Catalyst runs at low pressure!: <https://phys.org/news/2017-06-efficient-low-temperature-catalyst-hydrogen-production.html>

Similar article on work at Lehigh U & Dalian U: <https://phys.org/news/2017-09-closer-hydrogen-powered-cars.html>

**4)** **New Leaf: CO2 Back To Fuel**, 07/29/16, Argonne National Lab & Illinois State U. have developed a highly efficient way to convert CO2 + H20 into CO & O, using tungsten diselenide as a catalyst and sunlight. From: <https://www.anl.gov/articles/new-leaf-scientists-turn-carbon-dioxide-back-fuel>

**5) Why not split harmful carbon dioxide into harmless carbon & oxygen**? (+ H2 along the way )

By James Miller, 07/07/09, Scientific American - Excerpt: “At Sandia NL, we are working to apply concentrated sunlight to drive high-temperature reactions that yield carbon monoxide, **H2** & oxygen from CO2 & water.”

From: <https://www.scientificamerican.com/article/splitting-carbon-dioxide/>

**6) Porous Material Converts CO2 into Carbon Monoxide and Oxygen** By Bob Yreka, 08/21/15, Physics.org - Lawrence Berkeley National laboratory also collaborated with the University of California to develop a porous material that splits carbon dioxide molecules into carbon monoxide and oxygen.

From: <https://phys.org/news/2015-08-porous-material-co2-carbon-monoxide.html>

**More Bridge Fuel Options from CO2 Reuse (4)**

**1) Energy Source Innovation Stream: Carbon Smart Circular Economy**, Atlantic Council Interview, 4/29/20.

Randolph Bell, GEC Director, interviewed CEO, Dr. Jennifer Holmgren, **LanzaTech** on CO2 to synfuel process. **Excerpt**: “On cost gap between LanzaTech’s sustainable aviation fuel and oil, Dr. Holmgren said her firm’s method can compete in an $80 barrel environment.” Oil is now $81, 10/11/21. See: https://www.lanzatech.com

From: <https://www.atlanticcouncil.org/event/energysource-innovation-stream-carbonsmart-circular-economy/>

**2) Directly Converting CO2 Into a Gasoline Fuel** By Wei, Jian *et al*. *Nature Communications.* 8, 15174 doi: 10.1038/ncomms15174 (2017). Dr. Jian Wei, et al report final results from an extensive study for the Dalian National Laboratory for Clean Energy and Dalian Institute. Excerpt: “Here we report a highly efficient, stable and multifunctional Na–Fe3O4 /HZSM-5 catalyst, which directly converts CO2 to gasoline-range (C5–C11) hydrocarbons with selectivity up to 78%... under industrial relevant conditions.”

Same lab produces fusil alcohols and much more. From: <https://www.nature.com/articles/ncomms15174>

**3) OPUS 12 – RECYCLING CO2 BACK INTO FUELS AND CHEMICALS – White Paper, 2012**

By Nicholas Flanders, Opus 12, Cyclotron Rd, Lawrence Berkeley Nat’l Lab, Stanford University, SLAC

Opus 12, Inc. is a prominent US R&D company that developed out of Stanford and LBNL. Excerpt: “Using only water and electricity as inputs, we have demonstrated the electrochemical reduction of carbon dioxide (ECO2R) to 16 different products, including ethylene, ethanol, and syngas, which can be upgraded to carbon-neutral diesel, jet fuel, or gasoline.” They also claim, “We have exceeded the best-known published performance for CO2 reduction by a factor of 5X.” From LBNL: <https://ei.haas.berkeley.edu/education/c2m/docs/2016%20Finalists/Opus%2012.pdf>

From Stanford University: <https://tomkat.stanford.edu/innovation-transfer/opus-12>

**4)** **Test Facility Begins Capturing Carbon from Air** – “Pilot plant in Canada demonstrates carbon capture on an industrial scale” by [Richard Martin](https://www.technologyreview.com/profile/richard-martin/), MIT Technology Review, Oct. 9, 2015. With support from Bill Gates, Carbon Engineering has been operating their new “Air to Fuel” plant for 3+ years. See: <http://carbonengineering.com> /

See: [www.technologyreview.com/s/542226/test-facility-begins-capturing-carbon-from-air/](http://www.technologyreview.com/s/542226/test-facility-begins-capturing-carbon-from-air/)

**5)** **Two new ways to turn ‘garbage’ CO2 into fuel**, by Robert Service, Science Mag., 9/17 With ARPA support, Dioxide Materials has developed two efficient ways to convert CO2 + H20 + watts into CO, methanol and/or synthetic diesel. The first uses silver & iridium oxide catalysts in a liquid electrolyte containing imidazolium. They claim efficiency is twice that of comparable electrolyzers:

From: <http://www.sciencemag.org/news/2017/09/two-new-ways-turn-garbage-carbon-dioxide-fuel>.

MIT study: <https://phys.org/news/2016-11-greenhouse-gas-gasoline.html>

**6) Proven one-step process to convert CO2 and water directly into liquid hydrocarbon fuel**

02/22/16, Physics.org – Excerpt: ”A team of University of Texas at Arlington chemists and engineers have proven that concentrated light, heat and high pressures can drive the one-step conversion of CO2 and water directly into useable liquid hydrocarbon fuels.” From: <https://phys.org/news/2016-02-proven-one-step-co2-liquid-hydrocarbon.html>

**7) First Low-Cost System for Splitting Carbon Dioxide,** 06/05/17, EPFL – Excerpt: “The lab of Dr. Michael Graetzel at EPFL has developed an Earth-abundant catalyst based on copper-oxide nanowires modified with tin oxide. The system splits CO2 with an efficiency 13.4% …to produce carbon-based fuels from CO2 & water.” From: <https://phys.org/news/2017-06-low-cost-carbon-dioxide.html>

**8) Fuel From Artificial Leaf** – Technology That Mimics Photosynthesis Converts CO2 To Fuels by Javier Garcia Martinez, Dec.’17, Scientific American – Excerpt: “In a June ‘16 issue of Science, Daniel Nocera & Pamela Silver, et al, at Harvard, reported their approach that combines water splitting with CO2 conversion into fusel alcohols that far exceeds leaf conversion of CO2 into carbohydrates.”

**9) What Should We Make with CO2 & How Can We Make It?**, 03/29/18, Toronto U. By Aleksandra Bushuyev, Phil De Luna, et al, Excerpt: “We propose the gradual rise of photocatalytic, CO2 polymerization, biohybrid, and molecular machine technologies to augment and enhance already practical electrocatalytic CO2 conversion methods.” [www.cell.com/joule/fulltext/S2542-4351(17)30076-4](http://www.cell.com/joule/fulltext/S2542-4351%2817%2930076-4)

**Related Articles & Websites:**

ARPA-E: <https://arpa-e.energy.gov/?q=slick-sheet-project/converting-co2-fuel-and-chemicals>

North Carolina State U: <https://phys.org/news/2017-08-bar-water-splitting-co2-splitting-techniques.html>

From Oakridge: <http://www.snopes.com/2016/10/19/method-to-convert-co2-into-ethanol/>

Liquid Light: <http://e360.yale.edu/features/using_co2_to_make_fuel_a_long_shot_for_green_energy>

Biochar Study: Carbon Abatement, Gasification, Bioenergy, Biochar, UC Davis -Pereira, Suddick, Six‘16

From: <http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0150837>

# Carbon Leads Way in H2 Energy, 03/16, Griffith U. [https://phys.org/news/2016-03-carbon-energy.html](https://phys.org/news/2016-03-carbon-energy.html%22%20%5Ct%20%22_blank)

**H2 Production from Advanced Electrolysis** **(5)**

The following links provide a small sample of reports on recent advances in electrolysis R&D.

<https://phys.org/news/2016-03-efficiency-electrolysis.html> (Electrolysis Efficiency Doubled, they claim.)

<https://phys.org/news/2017-06-scalable-fuels-future-hydrogen-economy.html>

<https://phys.org/news/2014-09-hydrogen-production-breakthrough-herald-cheap.html>

[https://phys.org/news/2018-03-hydrogen-breakthrough-game-changer.html](https://phys.org/news/2018-03-hydrogen-breakthrough-game-changer.html%22%20%5Ct%20%22_blank)

<https://arpa-e.energy.gov/?q=slick-sheet-project/high-efficiency-hydrogen-production-0>

<https://www.sciencedaily.com/releases/2011/09/110919151317.html> / <http://www.hydrogenenergy.co.uk>

<https://cleantechnica.com/2015/08/20/lowdown-solar-hydrogen-power-gas-epfls-graetzle/>

<http://www.labmanager.com/news/2017/08/scientists-extract-hydrogen-as-potential-fuel-source#.Wc1xDRQsHlJ>

[www.innovationtoronto.com/2017/03/a-new-approach-to-the-production-of-hydrogen-from-water-using-solar-energy](http://www.innovationtoronto.com/2017/03/a-new-approach-to-the-production-of-hydrogen-from-water-using-solar-energy)

<https://phys.org/news/2017-09-self-healing-catalysts-easier-solar-energy.html>

[https://www.technologyreview.com/s/409464/cheap-hydrogen/](https://www.technologyreview.com/s/409464/cheap-hydrogen/%22%20%5Ct%20%22_blank) / [https://phys.org/news/2016-03-carbon-energy.html](https://phys.org/news/2016-03-carbon-energy.html%22%20%5Ct%20%22_blank)

<https://www.popularmechanics.com/science/energy/a26884433/scientists-are-now-transforming-saltwater-into-hydrogen-fuel/>

<https://www.chemistryworld.com/news/magnets-that-double-efficiency-of-water-splitting-could-help-usher-in-a-hydrogen-economy/3010618.article>

**Green Ammonia Sources**:

**NH3 Fuel Association;** <https://nh3fuelassociation.org/> - huge network and clearing house on NH3 for fuel.

**Sturman Industries** makes the world’s most advanced engines & hydraulic systems employed by NASA, Siemens, many others & specialize in NH3 process & utilization: see [www.sturmanindustries.com](http://www.sturmanindustries.com).

**Ammonia - a renewable fuel, could power globe without carbon,** By Robert Service, 7/12/18

[www.sciencemag.org/news/2018/07/ammonia-renewable-fuel-made-sun-air-and-water-could-power-globe-without-carbon?utm\_campaign=news\_daily\_2018-07-12&et\_rid=301944820&et\_cid=2178830](http://www.sciencemag.org/news/2018/07/ammonia-renewable-fuel-made-sun-air-and-water-could-power-globe-without-carbon?utm_campaign=news_daily_2018-07-12&et_rid=301944820&et_cid=2178830) /

**Hydrogen Production via Aluminum/Water Process**

**1)** **Nano Aluminum Offers Fuel Cells On Demand – just add water**, by David Hambling, 08/03/17: Scott Grendahl, et al., US Army Lab., Aberdeen, MD uses nano-aluminum & H2O to make H2. No electricity needed. They claim their process is nearly 100% efficient. Process produces & stores H2.

From: <https://www.newscientist.com/article/2142693-nano-aluminium-offers-fuel-cells-on-demand-just-add-water/>

Also: **H2 Comeback Could Make Elon Sweat**, By Nick Rice, 03/17/18, <https://impact4all.org/the-hydrogen-revival/>

**2) Safe efficient H2 from aluminum & water for in-flight aircraft,** 4/25/17, Phys.org

Technion-Israel Institute of Technology has patented an in-flight process to store and produce H2 from water and aluminum particles safely and cheaply. Published in *International Journal of Hydrogen Energy*.

From: <https://phys.org/news/2017-04-safe-efficient-hydrogen-aluminum-particles.html>

**3)** The aluminum approach to H2 production & storage needs a cleaner, cheaper way to make aluminum. Now, with a grant from ARPA-E and MassCEC, Infinium Corp has perfected a new electro-chemical cell that separates the metal from its ore *without generating carbon dioxide*, a by-product of traditional methods. They claim their process is *50 per cent more* energy-efficient then current practice. From:

[www.newscientist.com/article/mg22530102-300-cheap-wonder-metals-will-make-a-faster-cleaner-world/](http://www.newscientist.com/article/mg22530102-300-cheap-wonder-metals-will-make-a-faster-cleaner-world/)

<http://www.infiniummetals.com/news_item.php?id=163>

**Implications: H2 & Synfuel Production from H2O & CO2** (Brookhaven / Peking / Dalian, among others - see p.3)

**1)** CO2 from coal, oil, gas, wood & biofuel plants, and in time from ambient air, can be converted with H2O into CO or various bridge fuels, as well as **H2** along the way. H20 is reconstituted or passed through or converted to H2 and oxygen. CO is a valuable industrial feedstock. Process is generally as follows:

a) CO2 + H2O + Sunlight or watts make CO & H2O or CO & **H2** & O. (Arg.-Ill./Diox Matrls/Sandia-LBNL)

b) CO + H2O make pure **H2** and CO2 byproduct. (Brookhaven - Peking U. / Dalian U., Lehigh U.)

c) CO2 + H2O + Sunlight or watts make CO & H2O or CO & **H2** & O. (Arg.-Ill./Diox Matrls/Sandia-LBNL)

Process can recycle CO2 with CO & H2O in a loop to make H2, then other fuels. Coal, gas, oil, cement, NH3 and biomass power plants all qualify for this approach. In theory, distributed plants can remove CO2 from the air, i.e. Opus 12, Climeworks and CE. Many labs make similar claims. Core process has been self-evident for decades. What is new; each step is now cost effective for central plants. Distributed DAC is too expensive in present form.

**2)** Major advances in electrolysis have brought **H2** production from water to the point of commercial viability. A small sampling is cited above. Electrolysis research is constantly expanding and advancing.

**3)** **H2** production & storage via H2O/Aluminum system is now cost-effective (Aberdeen/Technion/Infinium).

**Recap & Further Discoveries** **(6)**

We are stuck with coal, gas, oil, ammonia, aluminum, concrete, steel, paper, plastic and other plants that emit massive CO2. Many hundreds more are being planned and built which will negate any progress on emissions for the foreseeable future. For economic and political reasons, it is very difficult to close them down en masse any time soon. They stand directly in the path of sane climate and sustainable energy goals. Therefore, whatever else happens, CO2 from central plants must be captured and reused to make H2, NH3, methane, methanol or other bridge fuels & feedstocks or those plants will have to close. Central plant operators can profit nicely by reducing costs and emissions and collecting carbon offsets or RECs all at once if the right carbon accounting system is in place. Though hardly ideal ‘45Q’ tax credits from the recent budget deal may give us what we need for now. See:

 [www.centerforcarbonremoval.org/blog-posts/2018/2/15/federal-budget-bill-includes-massive-tax-credits-for-carbon-capture](http://www.centerforcarbonremoval.org/blog-posts/2018/2/15/federal-budget-bill-includes-massive-tax-credits-for-carbon-capture)

CO2 Reuse at central plants might actually spur the development of distributed DAC by driving down the cost of their catalysts and making it easier to combine them with power & storage operations. Presently though there seems to be a false debate between some DAC proponents versus arguments for CO2 Reuse at central plants. As noted, DAC, in its present form, is more expensive then harvesting CO2 from power plants for various reasons but chief among them is **a)** plant exhaust contains roughly 300 times more CO2 than ambient air and **b)** the high cost of electricity to run giant fans. However, catalysts for both approaches are similar or give similar results. Lowering the cost of one, can lower the cost of the other. A much better approach for DAC is to apply it to vehicles and HVAC systems in buildings wherein the flow of air is already paid for but that has not yet been developed.

Another hurdle to anticipate is that new methods to produce H2 via CO2/CO/H2O process, cited above, could lead to over production of CO, as so much CO2 is produced in the world and then it has to go somewhere. Fortunately, NASA’s Langley Research Center has developed a highly efficient Low Temperature Oxidation Catalyst (LTOC) that turns CO into CO2 *without burning it.* Resulting CO2 can be reused again with H2O to produce more H2, then methane, methanol, carbonates or CNTs. LTOC runs at room temperature and will greatly improve the performance of catalytic converters for combustion vehicles. The inventors won the 2012 NASA Commercial Invention of the Year Award for "Methodology for Effective Stabilization of Tin Oxide-Based Oxidation/Reduction Catalysts." From: <https://www.nasa.gov/centers/langley/news/researchernews/rn_2012InventionAward.html> .

The main point is that CO2 & H2O are feedstocks for a) H2, b) NH3, c) methane, d) methanol, e) ethanol, f) diesel, g) CNTs and g) carbonates to make clean watts, alternate fuels and other products, i.e. plastic, concrete & fertilizer.

**CO2 into Methanol and Plastics**

**1) Chemists ID Catalytic ‘Key’ for Converting CO2 to Methanol** - New catalysts convert CO2 to CH3OH, 03/23/17, DOE/BNL / Excerpt: “Brookhaven scientists have identified a zinc/copper (Zn/Cu) catalyst that transforms CO2 + H2 into methanol, a potential fuel and feedstock.”

From: [www.sciencedaily.com/releases/2017/03/170323141417.htm](https://www.sciencedaily.com/releases/2017/03/170323141417.htm)

**2) Researchers Can Now Convert CO2 From The Air Directly Into Methanol Fuel**

By Fiona MacDonald, 01/28/16, Phys.org, describes method from South Carolina U that takes CO2 from air to produce methanol for fuel & feedstock for plastics. Published; [American Chemical Society.](http://pubs.acs.org/doi/abs/10.1021/jacs.5b12354) From:

<https://www.sciencealert.com/researchers-can-now-convert-captured-co2-directly-into-methanol-fuel>

**3) Here’s a sweet recipe for cheap, green plastic - sugar & corncobs,** By Roni Dengler,

Science Magazine, Jan. 26, 2018 - Excerpt: “Now, a team of researchers at Wisconsin U. in Madison have invented an inexpensive way to make plastic with a much lighter touch, from sugar & corncobs. If it can be made cheaply enough, the material could one day replace one of the world’s most common plastics, polyethylene terephthalate (PET) - found in food packaging, soda bottles, and polyester fabric.”

From: <http://www.sciencemag.org/news/2018/01/here-s-sweet-recipe-cheap-green-plastic-sugar-and-corncobs?utm_campaign=news_daily_2018-01-26&et_rid=301944820&et_cid=1814095>

**4) Scientists Make Plastic from Sugar & Carbon Dioxide,** 6/13/17, By Vicky Just, Phys.org

From: <https://phys.org/news/2017-06-scientists-plastic-sugar-carbon-dioxide.html>

**5) These 5 Companies Strive to Convert CO2 to Cash** – By Heather Clancy, Sept. 22, 2014, GreenBiz

From: <https://www.greenbiz.com/blog/2014/09/22/5-companies-convert-co2-cash>

**6) Recycling Carbon Dioxide To Make Plastics**, DOE Office of Fossil Energy, May 20, 2013,

From: <https://energy.gov/fe/articles/recycling-carbon-dioxide-make-plastics>

**Converting CO2 into Nanofibers, Nanotubes & Cement (7)**

**1) Researchers Assess Power Plants that Convert CO2 into Carbon Nanotubes,**

by Lisa Zyga, June 20, 2016 - GWU Researchers claim their process converts CO2 gas directly into carbon nanotubes (CNTs). They claim their technology can “completely eliminate power plants CO2 emissions” while producing many new products, including batteries & structural components.

Concept is well proven. From: <https://phys.org/news/2016-06-power-co2-emissions-carbon-nanotubes.html>

Similar: <https://phys.org/news/2015-08-diamonds-sky-approach-co2-valuable.html#nRlv>

**2) Transforming Greenhouse CO2 into Carbon Nanotubes**, By Mike Berger, 03/21/17

Similar process from GWU converts CO2 to Cement; “Per ton CO2 avoided, the C2CNT cement plant consumes $50 electricity, emits no CO2, produces $100 worth of cement and ∼$60,000 of CNTs.”

From NanoWerk: [https://www.nanowerk.com/spotlight/spotid=46170.php](https://www.nanowerk.com/spotlight/spotid%3D46170.php)

**DOE Reports - CO2 Conversion to Carbonates & Cleaner Fuels**

Direct CO2 Mineralization to carbonates is still much preferred by many DOE labs and other research centers. The following DOE reports and sites below provide a useful introduction.

**1) Accelerating Breakthrough Innovation in Carbon Capture & Storage, Sept., ‘17**

The Office of Fossil Energy and Oak Ridge National Lab have compiled a voluminous report on CO2 utilization.

<https://www.energy.gov/sites/prod/files/2018/05/f51/Accelerating%20Breakthrough%20Innovation%20in%20Carbon%20Capture%2C%20Utilization%2C%20and%20Storage%20_0.pdf>

**2) Innovative Concepts For Beneficial Reuse of Carbon Dioxide,** July 2010, DOE, OFE

US Energy Secretary Steven Chu approved a funding report on CO2 reuse options, especially mineralization: <https://energy.gov/fe/innovative-concepts-beneficial-reuse-carbon-dioxide-0>.

**3) DOE Invests $5.9 Million to Advance Novel CO2 Utilization Strategies** 01/22/17 – A follow-up report on mineralization is here; <https://energy.gov/fe/articles/department-energy-invests-59-million-projects-advance-novel-co2-utilization-strategies>

**Related Research & Policy Centers:**

European Union Commission (‘to fight climate change’) website; <https://ec.europa.eu/clima/index_en>

Carbon Capture Coalition: <http://carboncapturecoalition.org/legislation/>

Center for Negative Carbon Emissions: Director, Klaus Lackner, <https://cnce.engineering.asu.edu>

Center for Carbon Removal <http://www.centerforcarbonremoval.org>

Clean Energy Research Center, UBC: <http://cerc.ubc.ca/research/carbon/>

Center, Capture, Conversion of CO2: [www.brown.edu/research/projects/capture-and-conversion-of-co2/](http://www.brown.edu/research/projects/capture-and-conversion-of-co2/)

Global CCS Institute offers complete review of CCS technology: <https://www.globalccsinstitute.com>

DOE Frontier Energy Research Centers (EFERCs): <https://science.energy.gov/bes/efrc/centers/>

Lenfest Center, Sustainable Energy at [Earth Institute, Columbia University](https://en.wikipedia.org/wiki/Earth_Institute): <http://energy.columbia.edu>

US Biochar Initiative: <http://biochar-us.org>

**On Terrestrial Sequestration:**

Tribal Energy & Environmental Information: On Terrestrial Sequestration of CO2:

<https://teeic.indianaffairs.gov/er/carbon/apptech/terrapp/index.htm>

The Plains CO2 Reduction (PCOR) Partnership: On Terrestrial Sequestration of CO2: <http://www.undeerc.org/PCOR/region/terrestrial/default.aspx>

**Biomass Fuels**

**Vast bioenergy plantations could stave off climate change & radically reshape planet**, By Julia Rosen, 2/18/18

<http://www.sciencemag.org/news/2018/02/vast-bioenergy-plantations-could-stave-climate-change-and-radically-reshape-planet?utm_campaign=news_weekly_2018-02-16&et_rid=301944820&et_cid=1855583>,

**Hemp produces viable biodiesel, study finds**,10/06/10, By Christine Buckley, U. of Conn.,

From: <https://phys.org/news/2010-10-hemp-viable-biodiesel.html>

**Hemp as Fuel/Energy Source**, by Jeremy Briggs; <http://www.hemphasis.net/Fuel-Energy/fuel.htm>

(Reviews pyrolysis for hemp processing)

Related: Utilization of Biomass Pyrolysis For Energy Production, Soil Fertility & Carbon Sequestration

*Summary presented May 7, 2007 at the UN Commission on Sustainable Development Partnerships Fair – Partnership, New Technologies, Small Island Developing States,* By Hawkins, Nilsson, Oglesby & Day From: <http://www.carbonchar.com/sites/default/files/UN%20SIDS%20CSD-15%20paper.pdf>

Related**:** Carbon Abatement, Gasification, Bioenergy & Biochar, ‘16, UC Davis – Pereira, Suddick & Six

From: <http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0150837>

**Notable Companies: (8)**

CarbonClean: [www.carboncleansolutions.com](http://www.carboncleansolutions.com)/ New Light: [www.newlight.com](http://www.newlight.com)

Global Thermostat: <http://globalthermostat.com> / Climeworks: <http://www.climeworks.com>

Carbon Engineering: <http://carbonengineering.com> / Algenol; <http://algenol.com> / There are many more.

**Review**

It may take a long time to establish an effective, consistent, worldwide carbon policy and other supportive measures that are clearly needed to protect and restore Climate and grow the world economy. Meanwhile, lucrative CO2 & H2 based solutions have arrived that will strengthen the case for Sustainable Energy, Distributed Energy, Energy Storage and Carbon Pricing as well. All but the most decrepit central plants can now be profitably transformed from CO2 emitters into CO2 harvesting centers that generate and store power by simultaneously producing clean watts, H2, NH3, methane, methanol and/or other fuels & feedstocks. In this way, existing power plants can evolve in two stages from dire climate liabilities into prodigious climate assets.

Finally, combined power and storage can pave the way for grid-connected, distributed renewables and other Decentralized Energy Alternatives. Utility-scale storage is increasingly vital for grid security and to back up wind and distributed, ‘net-metered’ PV. Even now, DEA markets would be severely set back by the high cost of storage if not for the firming and back-up power of the grid itself. Net-metered PV needs a stable grid. As net-metered PV proliferates, the need for grid stability and therefore central storage can only increase. Over time, battery cost will decline with more hard orders, boosting distributed storage, still too expensive, i.e. Tesla Power Wall = $3-4K.

To sum, Central Power & Storage can benefit and help grow DEA markets in the next crucial 10 years, while simultaneously reducing CO2 emissions and reducing atmospheric CO2 as well. Plant operators and owners can benefit from lower fuel costs, carbon offsets and storage operations based on daily kWh price differentials. Again, 45Q law is hardly ideal but still a stepping-stone toward CO2 Reuse projects.

**Request For Proposals (RFPs) - Lemons to Lemonade**

CO2 gas is sour lemons. Let’s squeeze the lemons, add water, knowledge and honey which is money to make sweet lemonade. Public Service Departments and Local Utilities across this great land of ours, and all great lands, can explore the new chemistry to prepare new RFPs, based on these new catalysts, cited above. Each ‘Request for Proposal’ should call for a ‘Transformative Project’ to upgrade and convert an existing fossil power plant or plants in two stages to negative carbon emissions. These projects should be of sufficient size to demonstrate larger economies of scale and conceived as profitable ventures.

Mainstream climate organizations, such as Sierra, CLF, EDF and the Public Interest Research Groups should take full advantage of these new discoveries to advance their own climate and energy goals and to promote economic growth. Closing coal plants is fair with no better choice but negates the opportunity to transform them *profitably* to Negative Carbon Stations that consume biofuels produced from biomass from farms and from CO2 from the air.

The United Nations and The World Bank, among other international leaders and lenders, should champion these pioneering efforts or else their own environmental and economic agendas will be severely compromised. In short, there is no way to solve our climate and energy crisis without a specific CO2 fix for central plants. The CO2 threat posed by central plants cannot be subsumed under a general commitment to renewables and efficiency because that will take too long to be effective. We need a fast, expedient and profitable solution for power plants that will turn them from environmental and financial time bombs into working assets for sustainability and healthy climate. Down the road, the same CO2 Reuse methods can be applied to vehicles and buildings.

To close, here are links for two NYT’s articles and one for BCG Henderson Institute on coal numbers:

**As Beijing Joins Climate Fight, Chinese Companies Build Coal Plants,** [Hiroko Tabuchi](http://www.nytimes.com/by/hiroko-tabuchi), 07/30/17

<https://www.nytimes.com/2017/07/01/climate/china-energy-companies-coal-plants-climate-change.html>

**China’s Ambitious Plan to Curb CO2 Emissions**, by Keith Bradsher, Lisa Friedman, NYTs, 12/19/17

<https://www.nytimes.com/2017/12/19/climate/china-carbon-market-climate-change-emissions.html>

**Why Coal Will Keep Burning,** 03/28/18, BCG Henderson Institute, - Renewables are growing fast but not fast enough to save us. See: [https://www.bcg.com/en-gb/publications/2018/why-coal-will-keep-burning.aspx](https://www.bcg.com/en-gb/publications/2018/why-coal-will-keep-burning.aspx%22%20%5Ct%20%22_blank)

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