Flameless: HCCI

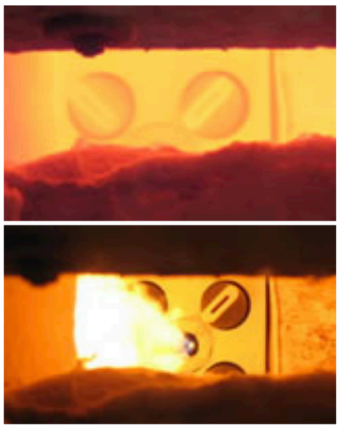
1

- Homogeneous charge compression ignition
- Gasoline engine: premixture, compress, then spark → premixed flame propagation
- Diesel engine: air, compress, then inject fuel which autoignites and burns as a nonpremixed flame
- HCCI, premixture compressed to autoignition point, homogeneous burning
  - Usually lean
  - Higher compression ratios, lower peak temperatures
  - High efficiency, low emissions
- Multi-fuel operation
- Hard to control, cold start issues

Flameless: MILD Combustion

2

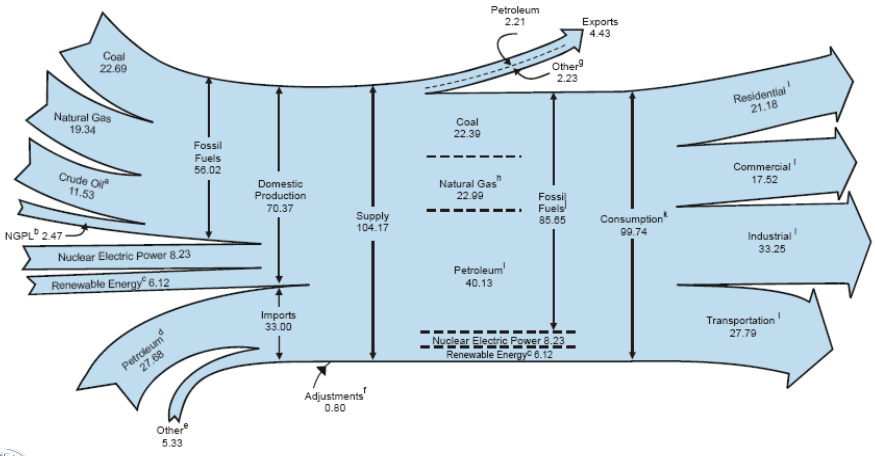
- Moderate or intense low oxygen dilution
- Quickly mix fuel, air, and recirculated products.
  - High temperature (but lower than flames), and high dilution.
- Avoids flame extinction/reignition processes.
- Lower temperature, distributed reaction
- Reduce peak flame temperatures
- Reduce NOx and soot emissions.
- Higher fuel flexibility



http://www.ifs.tohoku.ac.jp/enerdyn/en/en_researches_hicot.htm

U.S. Energy Use

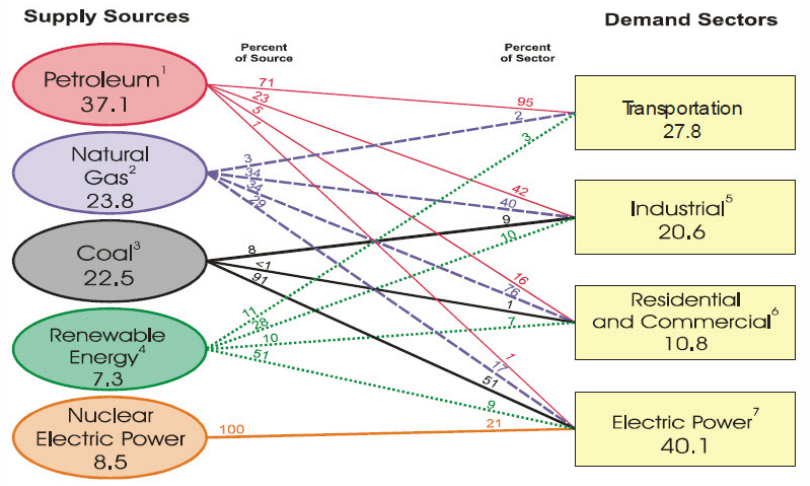
3



http://www.eia.doe.gov/emeu/aer/

U.S. Energy Use

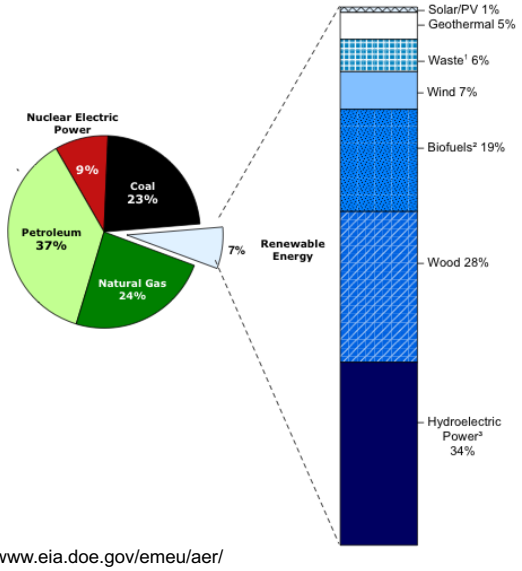
4



http://www.eia.doe.gov/emeu/aer/

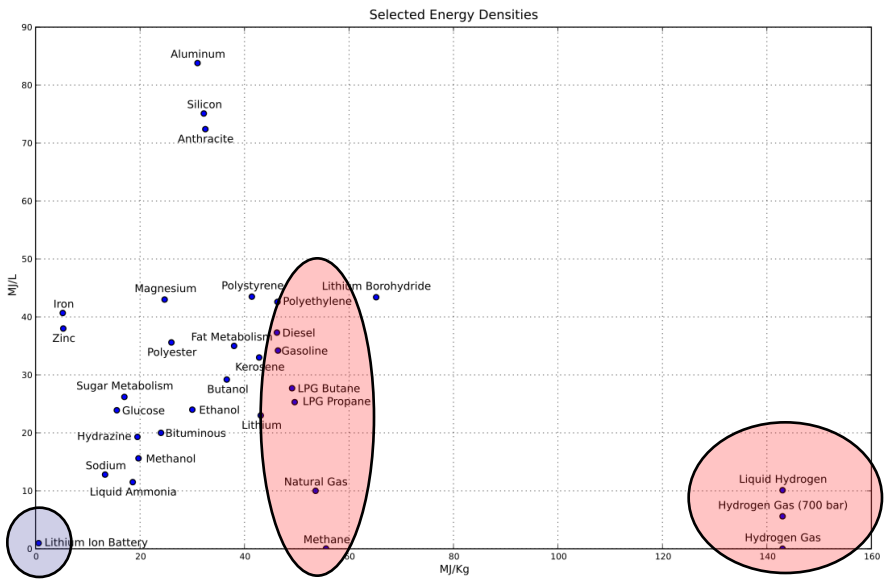
Non-combustion energy sources

- Non-combustion
  - Nuclear: 9%
  - Hydro: 2.4%
  - Wind: 0.5%
  - Solar: 0.1%
- Non-combustion sources will continue to increase, even substantially.
- Combustion will remain dominant in the forseeable future.



http://www.eia.doe.gov/emeu/aer/

Energy Density



http://upload.wikimedia.org/wikipedia/commons/c/c6/Energy_density.svg

Cubic Mile of Oil

- On an energy basis, the yearly coal, oil, and natural gas use is 3.0 cubic miles of oil.
  - www.eia.gov
- This is 1.6E20 J/year.
- Assume oil/coal/natural gas are converted to electricity using 34% efficient processes.
- The power to replace 1.6E20 J/year is 1.73E12 Watts.

CMO Replacements

- 1 CMO replaced by Hydroelectric dams
  - 192 Three Gorges Dams (biggest, China)
    - Build 1 per week for 3.7 years
    - 22,500 MW
    - 3.3 times bigger than the biggest in the U.S.
    - 11 times bigger than the Hoover dam
  - Or 1100 Average size dams
    - Build 1 per week for 21 years
    - 3,932 MW (average size above 2,000 MW)
  - There are only 70 plants above 2,000 MW
  - *Using 40% capcity factor (average in US)*
- 1 CMO replaced by Nuclear power plants
  - 290 Kashiwazaki-Kariwa Plants (biggest, Japan)
    - Build 1 per week for 5.6 years
    - 7,965 MW
  - Or 955 Average size plants plants needed
    - Build 1 plant per week for 18 years
    - 2,414 MW (average of plants above 1,000 MW)
  - There are only 152 plants above 1,000 MW
  - *Using 75% capacity factor (average in US)*

https://en.wikipedia.org/wiki/Hydroelectricity

http://japandailypress.com/tepco-believes-kashiwazaki-kariwa-plant-will-restart-next-year-0739191/

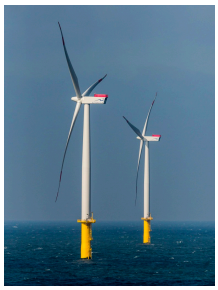
- https://en.wikipedia.org/wiki/Capacity_factor
- https://en.wikipedia.org/wiki/List_of_largest_hydroelectric_power_stations
- https://en.wikipedia.org/wiki/List_of_nuclear_power_stations

CMO Replacements

- 1 CMO replaced by Wind Mills
  - 3,084,000 average size land-based wind mills
    - Build 1,186 per week for 50 years
    - 1.65 MW (typical)
    - **8683** average size land-based wind farms
      - 586 MW each (avg size above 250 MW)
      - 355 Windmills each at 1.65 MW.
      - Build 5 farms a week for 33 years
    - Typical windmill = Vestas v18- 1.65 MW. 82 diameter, 83 m high tower
  - 1,413,400 average size off-shore wind mills
    - Build 544 per week for 50 years
    - 3.6 MW (typical)
    - **15,153** average size off-shore wind farms
      - 336 MW each (avg size above 200 MW
      - 93 Windmills each at 3.6 MW
      - Build 5 farms a week for 58 years
    - Typical windmill = Siemens SWT-3.6 3.6 MW. 120 m diameter, 90 m high tower
  - *Using 34% capcity factor (average in US)*
- 1 CMO replaced by Rooftop solar
  - 6.8 billion solar panels
    - 1 million per day for 19 years
    - 2.1 kW panels
    - Area = 16 m^2
    - Average American uses 1.2 kW*days.

  Using 12% capcity factor (average in US)

https://www.power-technology.com/projects/tuppadahalli-wind-farm/



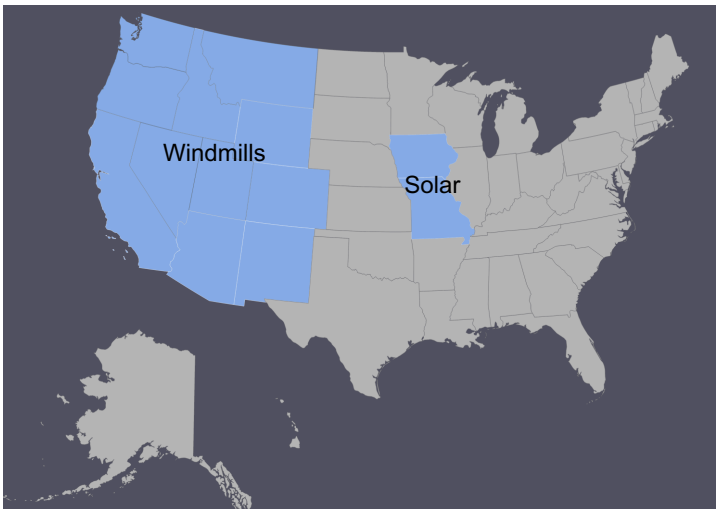
http://www.owp-butendiek.de/technology/wind-turbine/

2 Kw solar power plant.

https://www.solarenergypanels.in/solar-power-plants/1kw-2kw-5kw-10kw-on-grid-solar-power-plants

- https://en.wikipedia.org/wiki/Capacity_factor
- https://en.wikipedia.org/wiki/Wind_farm
- https://en.wikipedia.org/wiki/List_of_offshore_wind_farms
- https://en.wikipedia.org/wiki/List_of_onshore_wind_farms
- https://www.eia.gov/tools/faqs/faq.php?id=97&t=3
- https://www.solarenergypanels.in/solar-power-plants/1kw-2kw-5kw-10kw-on-grid-solar-power-plants

3 CMO



Combustion Issues

The High Cost of Cheap Coal

Coal is plentiful—and polluting. Can an energy-hungry world afford to wait for this fuel to clean up?

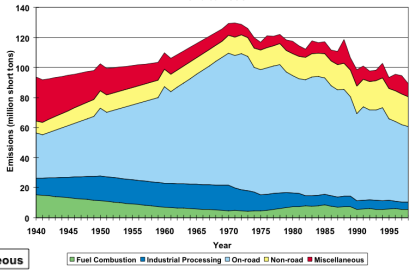
Combustion Issues

https://olsonfarlow.com/portfolios/mountaintop-removal

Emissions

- Emissions:
  - Pollutants
    - NOx
    - SOx
    - PM
    - Metals
  - Greenhouse Gases

Figure 3-2. Trend in CARBON MONOXIDE Emissions, 1940 to 1998



Fuel Combustion Industrial Processing On-road Non-road Miscellaneous

Figure 3-3. Trend in NITROGEN OXIDE Emissions, 1940 to 1998

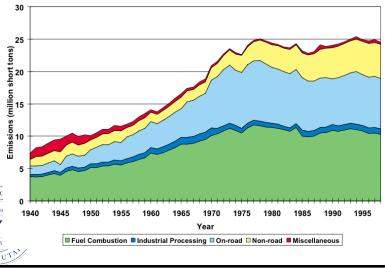
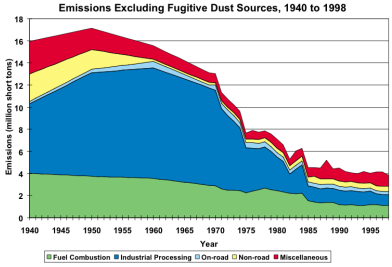
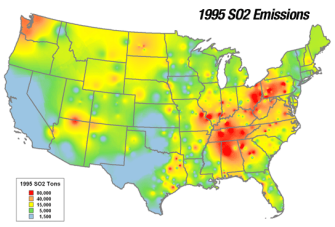


Figure 3-6. Trend in PARTICULATE MATTER (PM_{10}) Emissions Excluding Fugitive Dust Sources, 1940 to 1998



SO2 Emissions



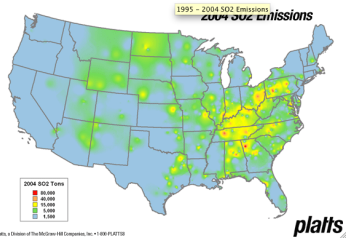
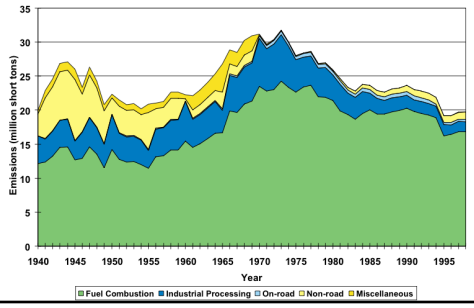


Figure 3-5. Trend in SULFUR DIOXIDE Emissions, 1940 to 1998



SO2 Emissions

U.S. coal-fired power plants invested more than $30bn on scrubbers in four years

http://www.power-eng.com/articles/2013/03/us-coal-fired-power-plants-invested-more-than-30bn-on-scrubbers-.html

Mar 25, 2013

Owners of coal-fired power plants invested more than $30 billion in flue gas desulfurization systems, also known as scrubbers, between 2007 and 2011, according to a report from the U.S. Energy Information Administration.

According to the report, scrubbers were installed at around 110 coal-fired power plants in 34 states during that time, raising the amount of scrubbed generating capacity in the U.S. from 115 GW to just more than 191 GW. That number represents a little less than 60 percent of coal-fired, steam electric generation capacity in the U.S.

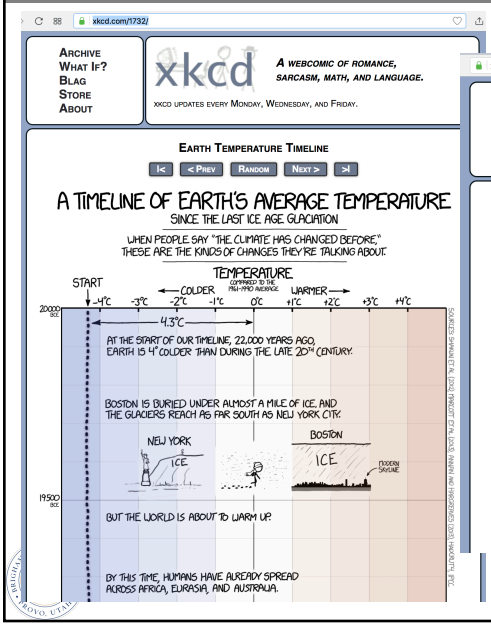
According to the EIA, utilities made the investments in scrubbers in response to several regulatory initiatives, including the U.S. Environmental Protection Agency's Clean Air Interstate Rule.

The increase in installed scrubbers has helped create a reduction of SO_2 emissions, which were 68 percent lower in 2011 than the 1990 level and 46 percent lower than the 2007 level. Other factors in that reduction include coal-fired plants burning less coal and switching to a lower sulfur coal.

Plant operators in Ohio, Pennsylvania, West Virginia, Maryland and Georgia made 43 percent of the total national investment in scrubbers, spending a total of $13 billion between 2007 and 2011, according to the EIA. Ohio plants spent more than any other state, making a $3.6 billion investment in scrubbers over that time period.

http://www.panoramio.com/photo/7780554

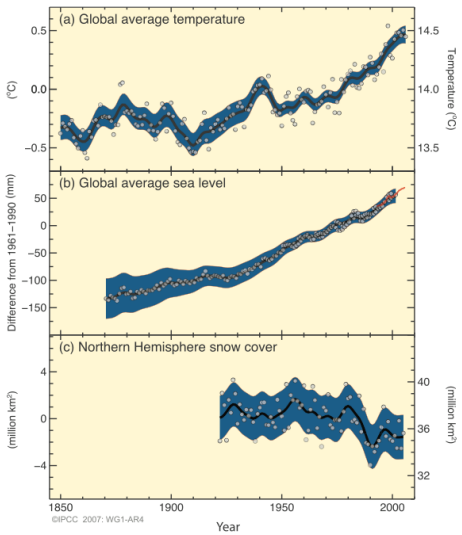
Temperature Rise



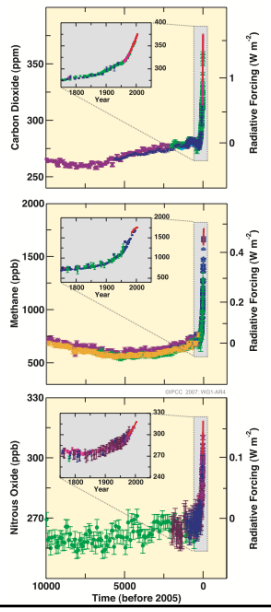
IPCC

- Intergovernmental panel on climate change.
- United Nations
- 1988
- Produce reports
  - 5 assessments reports: 1990, 1996, 2001, 2007, 2014
- 3 working groups
  - Physical Science Basis
    - Full report = 1552 pages
  - Impacts, Adaptation, Vulnerability
    - Full report = 1864 pages
  - Mitigation of Climate Change
    - Full report = 1454 pages
- Summary for policy makers (~30 pages)

Climate Change—IPCC

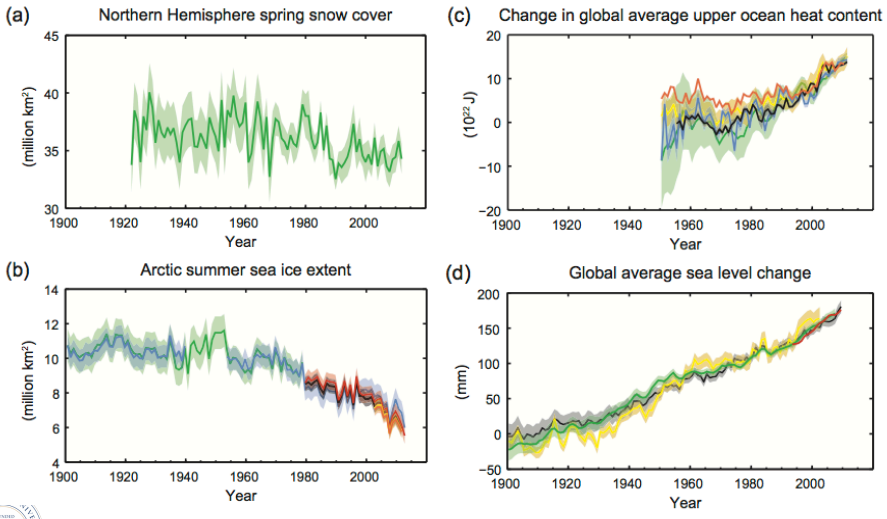


http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf



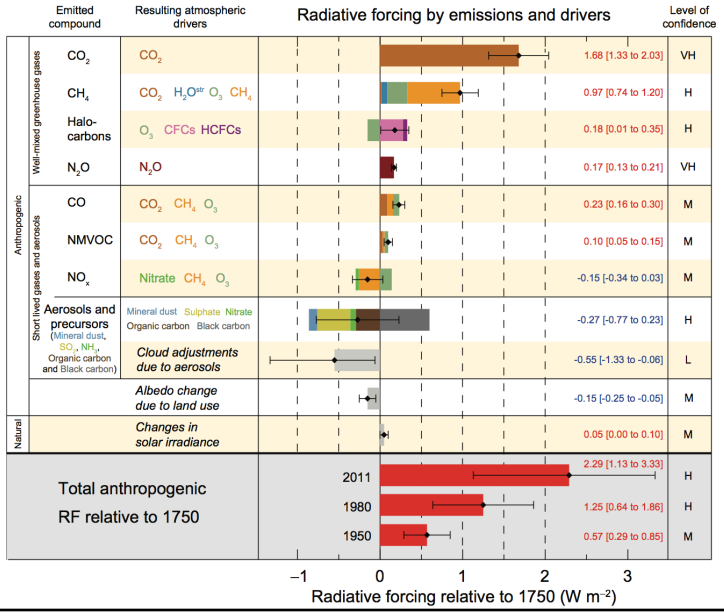
Climate Change--IPCC

19



IPCC—Radiative Forcing

20



Climate Models

23

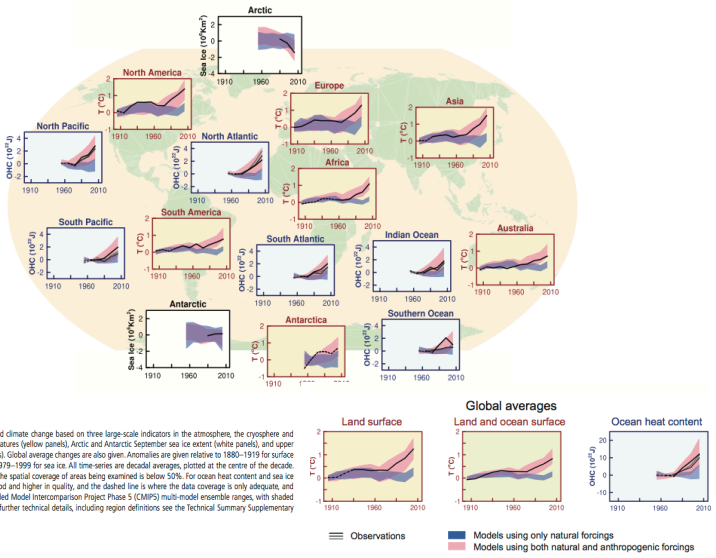


Figure SPM.6 | Comparison of observed and simulated climate change based on three large-scale indicators in the atmosphere, the cryosphere and the ocean: change in continental land surface air temperatures (yellow panels), Arctic and Antarctic September sea ice extent (white panels), and upper ocean heat content in the major ocean basins (blue panels). Global average changes are also given. Anomalies are given relative to 1880–1919 for surface temperatures, 1960–1980 for ocean heat content and 1979–1999 for sea ice. All time-series are decadal averages, plotted at the centre of the decade. For temperature panels, observations are dashed lines if the spatial coverage of areas being examined is below 50%. For ocean heat content and sea ice panels the solid line is where the coverage of data is good and higher in quality, and the dashed line is where the data coverage is only adequate, and thus, uncertainty is larger. Model results shown are Coupled Model Intercomparison Project Phase 5 (CMIP5) multi-model ensemble ranges, with shaded bands indicating the 5 to 95% confidence intervals. For further technical details, including region definitions see the Technical Summary Supplementary Material. [Figure 10.21; Figure TS.12]

Regulations

27

- New(ish) CO2 regulations
  - EPA March 2012
  - 1000 lbm CO2 per MW-hr for new coal plants
  - Typical plants emit ~1800
  - The limits are comparable to Natural Gas combustion emissions.
- Effectively requires sequestration for new coal plants.