The Health Benefits of Renewable Energy
Choices: A Role for Carbon Pricing
Dr. Jonathan Buonocore, ScD
5% chance of meeting 2°C, 1% chance of meeting 1.5°C

Less than 2 °C warming by 2100 unlikely

Adrian E. Raftery¹*, Alec Zimmer², Dargan M. W. Frierson³, Richard Startz⁴ and Peiran Liu¹
Global greenhouse gas emissions as implied by Intended Nationally-Determined Contributions compared to no-policy baseline, current-policy and 2 °C scenarios.
July 2017 tied for hottest

GISTEMP Seasonal Cycle since 1880

Seasonal cycle from MERRA2. Figure: NASA/GISS/GISTEMP
Three years to safeguard our climate

Christiana Figueres and colleagues set out a six-point plan for turning the tide of the world’s carbon dioxide by 2020.

Rapid deployment of renewable energy and retirement of coal
Decarbonization of buildings and city infrastructure
More electric vehicles and mass transportation
Reduce forest destruction
Decarbonize industry
Finance for climate mitigation
A roadmap for rapid decarbonization

Emissions inevitably approach zero with a “carbon law”

Global carbon law guiding decadal pathways

- Global CO₂ emissions
- CO₂ removal (GtCO₂/yr)
- CO₂ emissions from land use (GtCO₂/yr)
A roadmap for rapid decarbonization

Emissions inevitably approach zero with a “carbon law”
The ‘2°C capital stock’ for electricity generation: Committed cumulative carbon emissions from the electricity generation sector and the transition to a green economy

Alexander Pfeiffer a, b, Richard Millar a, c, Cameron Hepburn a, b, c, Eric Beinhocker a, d

Institute for New Economic Thinking, Oxford Martin School, University of Oxford, United Kingdom
Smith School for Enterprise and the Environment, University of Oxford, United Kingdom
Department of Physics, University of Oxford, United Kingdom
Blavatnik School of Government, University of Oxford, United Kingdom

HIGHLIGHTS

- Defines ‘2°C capital stock’ as infrastructure that gives a 50% chance of 2°C warming.
- The ‘2°C capital stock’ for electricity generation will be reached by 2017 on current trends.
- New electricity generation assets globally must then be zero carbon to avoid stranding, CCS or CDR.
- Risk of stranded assets is relevant to investors and policy makers.

No more fossil fuel power plants can be built to stay below 2°C
... and understanding risks from climate change.
What is pollution?
Why does pollution exist?
Definition and Implication of an Externality

• “Market failure” where a third party to a transaction incurs either costs or benefits involuntarily and does not receive or have to give payment for these costs or benefits

• Positive – flower garden. Your plants a garden, the neighborhood looks better, and the value of all homes in the neighborhood goes up, not just yours.

• Negative – traffic congestion. Many users on a road result in slower travel and higher accident risk for everyone.

• Market prices do not reflect full social costs and benefits, so markets cannot produce socially optimal results on their own
Diagram of a Negative Externality

- Price
- Quantity
- Demand
- Private Cost
- Private + Social Cost
- Ideal equilibrium
- Realized equilibrium

Private Cost vs. Private + Social Cost

Diagram indicating the differences between ideal and realized equilibriums due to negative externality.
“It is difficult to get a man to understand something, when his salary depends on his not understanding it.”

–Upton Sinclair
A Commons Problem – “Freedom in a Commons Brings Ruin to All” – Garrett Hardin
A Beautiful Mind (2001)
Quantifying the Influence of Climate on Human Conflict

Solomon M. Hsiang, * Marshall Burke, Edward Miguel

A Local violence East Africa

B Civil war incidence Sub-Saharan Africa

C Civil conflict onset Global tropics

13 SEPTEMBER 2013 VOL 341 SCIENCE www.sciencemag.org

Published by AAAS
Estimating economic damage from climate change in the United States

Solomon Hsiang,1,8‡ Robert Kopp,9‡ Amit Jina,4– James Rising,4,5‡ Michael Delgado,6 Shashank Mohan,6 D. J. Rasmussen,7 Robert Muir-Wood,6 Paul Wilson,6 Michael Oppenheimer,6 Kate Larsen,6 Trevor Houser6

Hsiang et al., Science 356, 1362–1369 (2017) 30 June 2017
Greenhouse Gases:
- CO2
- Methane (CH4)
- N2O

Air Pollutants:
- SO2
- NOx
- Particulates
- Ash
- Soot

“Co-benefits”

Actions that reduce these...

... can also reduce these...

...and have large benefits for public health.
Fine Particulate Matter

Figure II-1
DPM components

Health Effects of Air Pollution

- Premature mortality
- Heart Attacks
- Hospital admissions due to respiratory and cardiovascular causes
- Asthma exacerbations
- Lost days of school and work
- Possible link to autism and Alzheimer’s
- Other impacts to ecosystems – acid rain, crops and timber
Air pollution is 5th highest contributor to global burden of disease in 2013

The contribution of outdoor air pollution sources to premature mortality on a global scale

J. Lelieveld\textsuperscript{1,2}, J. S. Evans\textsuperscript{3,4}, M. F. Nais\textsuperscript{5}, D. Giannadaki\textsuperscript{2} & A. Pozzer\textsuperscript{1}

\textsuperscript{1}17 September 2015 | Vol 525 | Nature | 367
The Effect of Dose and Timing of Dose on the Association between Airborne Particles and Survival

Joel Schwartz,1,2,3 Brent Coull,4 Francine Laden,1,2,3 and Louise Ryan4

1Department of Environmental Health, and 2Department of Epidemiology, Harvard School of Public Health, Boston, Massachusetts, USA; 3Channing Laboratory, Brigham and Women’s Hospital, Harvard Medical School, Boston, Massachusetts, USA; 4Department of Biostatistics, Harvard School of Public Health, Boston, Massachusetts, USA

EPA PM$_{2.5}$

primary standard
$12$ µg/m$^3$

EPA PM$_{2.5}$

secondary standard
$15$ µg/m$^3$

Figure 1. The estimated concentration–response relation between PM$_{2.5}$ and the risk of death in the Six Cities Study, using a penalized spline with 18 knots. Also shown are the pointwise 95% CIs.
Exposed population × baseline mortality × concentration-mortality × air pollution level = Total Health Burden
Health Impacts of Fine Particulate Matter

- 130,000 to 320,000 premature deaths
- 180,000 non-fatal heart attacks
- 200,000 hospital and emergency room visits
- 2.5 million asthma exacerbations
- 18 million lost days of work

Estimating the National Public Health Burden Associated with Exposure to Ambient PM$_{2.5}$ and Ozone

*Risk Analysis, Vol. 32, No. 1, 2012*

Neal Fann,* Amy D. Lamson, Susan C. Anenberg, Karen Wesson, David Risley, and Bryan J. Hubbell
Health Impacts of Ground-Level Ozone

- 4,700 to 19,000 premature deaths
- 77,000 hospital and emergency room visits
- 11 million school absence days

Estimating the National Public Health Burden Associated with Exposure to Ambient PM$_{2.5}$ and Ozone

*Risk Analysis, Vol. 32, No. 1, 2012*
Neal Fann,* Amy D. Lamson, Susan C. Anenberg, Karen Wesson, David Risley, and Bryan J. Hubbell
The Recent and Future Health Burden of Air Pollution Apportioned Across U.S. Sectors

Neal Fann,* 1 Charles M. Fulcher, 1 and Kirk Baker 1

Published: March 18, 2013
Obama's clean power plan hailed as US's strongest ever climate action
AIR QUALITY CO-BENEFITS: FINE PARTICULATE MATTER (PM$_{2.5}$) IN THE YEAR 2020
SCENARIO 2: ENERGY SECTOR IMPROVEMENTS

This map shows changes in concentrations of PM$_{2.5}$ in Scenario 2 from the 2020 reference case. Scenario 2 is the moderate stringency, high flexibility & energy efficiency option and it results in widespread clean air co-benefits.

Units: PM$_{2.5}$ concentration in micrograms per cubic meter ($\mu g m^{-3}$)

Positive values = Increase in PM$_{2.5}$ | Negative values = Decrease in PM$_{2.5}$ | Coal plants locations from U.S. Energy Information Administration 2012, 2013
AIR QUALITY CO-BENEFITS: PEAK SUMMER OZONE IN THE YEAR 2020
SCENARIO 2: ENERGY SECTOR IMPROVEMENTS

Units: Ozone concentration in parts per billion (ppb)

-3.60 to -1.41
-1.40 to -1.01
-1.00 to -0.71
-0.70 to -0.51
-0.50 to -0.31
-0.30 to -0.01
0 to 0.70

LEGEND

Major Cities (>500,000)
Operating Coal Plants

THIS MAP SHOWS:
CHANGE IN CONCENTRATIONS OF PEAK SUMMER OZONE IN SCENARIO 2 FROM THE 2020 REFERENCE CASE. SCENARIO 2 IS THE MODERATE STRINGENCY, HIGH FLEXIBILITY & ENERGY EFFICIENCY OPTION AND IT RESULTS IN WIDESPREAD CLEAN AIR CO-BENEFITS.

Positive values = Increase in summer ozone | Negative values = Decrease in summer ozone | Coal plants locations from U.S. Energy Information Administration 2012, 2013
HEALTH CO-BENEFITS: LIVES SAVED IN THE YEAR 2020
SCENARIO 2: ELECTRICITY SECTOR IMPROVEMENTS

THIS MAP SHOWS:
THE CHANGE IN NUMBER OF PREMATURE DEATHS AVOIDED PER YEAR UNDER SCENARIO 2 FROM THE 2020 REFERENCE CASE BY STATE. SCENARIO 2 IS THE MODERATE STRINGENCY, HIGH FLEXIBILITY & ENERGY EFFICIENCY OPTION AND IT RESULTS IN THE LARGEST HEALTH CO-BENEFITS.

Units: premature deaths avoided per year
- Major Cities (>500,000)
- Operating Coal Plants

Positive values = increase in # of lives saved per year | Coal plant locations from U.S. Energy Information Administration 2012, 2013
HEALTH CO-BENEFITS: HOSPITAL ADMISSIONS AVOIDED IN THE YEAR 2020

SCENARIO 2: ELECTRICITY SECTOR IMPROVEMENTS

This map shows the changes in number of hospitalizations related to heart and lung disease under Scenario 2 from the 2020 reference case. Scenario 2 is the moderate stringency, high flexibility & energy efficiency option and it results in the largest health co-benefits.

Positive values = increase in # of hospital admissions avoided per year | Coal plant locations from U.S. Energy Information Administration 2012, 2013

LEGEND

- Major Cities (>500,000)
- Operating Coal Plants

Units: hospitalizations avoided per year

- 64 to 79
- 33 to 64
- 17 to 32
- 9 to 16
- 5 to 8
- 3 to 4
- < 1 to 2
Health Benefits Everywhere

An Analysis of Costs and Health Co-Benefits for a U.S. Power Plant Carbon Standard

Jonathan J. Buonocore¹, Kathleen F. Lamber², Dallas Burtraw³, Samantha Sekar³*, Charles T. Driscoll²
Health benefits > costs in most regions within 5 years

Fig 3. Net benefits by IPM Region for a moderately stringent, highly flexible carbon standard in 2020 (2010 USD) using central estimates for both.

An Analysis of Costs and Health Co-Benefits for a U.S. Power Plant Carbon Standard

Jonathan J. Buonocore¹*, Kathleen F. Lamber², Dallas Burtraw³, Samantha Sekar³*, Charles T. Driscoll²
Policy Choices Matter

- Scenario Comparison: lives saved per million tons of CO2 reduced
  - Scenario 1 (low stringency, low flex) = -0.2
  - Scenario 2 (moderate stringency, high flex) = 6.6
  - Scenario 3 (high stringency, moderate flex) = 3.
Court indefinitely halts suit on Obama new power plant rule

Amanda Reilly, E&E News reporter

Published: Thursday, August 10, 2017
What are the benefits of renewable energy or energy efficiency?
### Total Annual Benefits of Each Installation (million $)

<table>
<thead>
<tr>
<th>Location</th>
<th>Wind</th>
<th>PV</th>
<th>DSM Base &amp; Geothermal</th>
<th>DSM Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>North-Central Ohio</td>
<td>180</td>
<td>66</td>
<td>200</td>
<td>130</td>
</tr>
<tr>
<td>Chicago Area</td>
<td>210</td>
<td>37</td>
<td>160</td>
<td>46</td>
</tr>
<tr>
<td>Virginia</td>
<td>110</td>
<td>89</td>
<td>170</td>
<td>35</td>
</tr>
<tr>
<td>Cincinnati Area</td>
<td>210</td>
<td>100</td>
<td>200</td>
<td>20</td>
</tr>
<tr>
<td>Eastern PA</td>
<td>110</td>
<td>51</td>
<td>130</td>
<td>5.7</td>
</tr>
<tr>
<td>Southern New Jersey</td>
<td>110</td>
<td>68</td>
<td>120</td>
<td>80</td>
</tr>
</tbody>
</table>

---

**Health and climate benefits of different energy-efficiency and renewable energy choices**

Jonathan J. Buonocore¹,²,*, Patrick Luckow³, Gregory Norris¹,², John D. Spengler¹,², Bruce Biewald², Jeremy Fisher³ and Jonathan I. Levy¹,²,⁴
Benefits vary by type and place, but driven by health
Benefits ($) per amount of electricity produced

<table>
<thead>
<tr>
<th>Region</th>
<th>Wind</th>
<th>PV</th>
<th>DSM Base &amp; Geothermal</th>
<th>DSM Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>North-Central Ohio</td>
<td>150</td>
<td>110</td>
<td>150</td>
<td>99</td>
</tr>
<tr>
<td>Chicago Area</td>
<td>150</td>
<td>63</td>
<td>120</td>
<td>63</td>
</tr>
<tr>
<td>Virginia</td>
<td>91</td>
<td>120</td>
<td>130</td>
<td>44</td>
</tr>
<tr>
<td>Cincinnati Area</td>
<td>170</td>
<td>150</td>
<td>150</td>
<td>72</td>
</tr>
<tr>
<td>Eastern PA</td>
<td>81</td>
<td>81</td>
<td>95</td>
<td>14</td>
</tr>
<tr>
<td>Southern New Jersey</td>
<td>110</td>
<td>99</td>
<td>94</td>
<td>81</td>
</tr>
</tbody>
</table>

Levelized Cost of Energy in U.S. ($/MWh)

- Wind: $40 - $80
- PV: $140 - $320
- DSM Base & Geothermal: $30 - $150

Health and climate benefits of different energy-efficiency and renewable energy choices

Jonathan J. Buonocore¹,², Patrick Luckow³, Gregory Norris¹,², John D. Spengler¹,², Bruce Bierwald¹, Jeremy Fisher³ and Jonathan I. Levy¹,²,³

PUBLISHED ONLINE: 31 AUGUST 2015 | DOI: 10.1038/NCLIMATE2771
From 2007 to 2015, solar and wind power deployment increased rapidly while regulatory changes and fossil fuel price changes led to steep cuts in overall power-sector emissions.

We find cumulative wind and solar air-quality benefits of 2015 US$29.7–112.8 billion, mostly from 3,000 to 12,700 avoided premature mortalities, and cumulative climate benefits of 2015 US$5.3–106.8 billion.
Health and climate benefits of offshore wind facilities in the Mid-Atlantic United States

Jonathan Buonocore\(^1\), Patrick Luckow\(^2\), Jeremy Fisher\(^2\), Willett Kempton\(^1\) and Jonathan Levy\(^1\)

\(^1\) Center for Health and the Global Environment, Harvard University, Cambridge, MA 02138, USA
\(^2\) Synapse Energy Economics, Cambridge, MA 02139, USA

Environ. Res. Lett. 11 (2016) 074019

Keywords: renewable energy, co-benefits, climate mitigation, air quality, offshore wind
# Lives Saved By Wind Energy

<table>
<thead>
<tr>
<th>Type</th>
<th>Location and Size</th>
<th>Generation (GWh)</th>
<th>Lives Saved</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Offshore</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2017 - 1100 MW New Jersey</td>
<td>3700</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>2017 - 3000 MW New Jersey</td>
<td>10,000</td>
<td>55</td>
<td></td>
</tr>
<tr>
<td>2012 - 1000 MW Maryland</td>
<td>3100</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>2017 - 1000 MW Maryland</td>
<td>3200</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>2017 - 200 MW Maryland</td>
<td>650</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>2017 - 300 MW Maryland</td>
<td>970</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>2017 - 400 MW Maryland</td>
<td>1300</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>2012 - 1100 MW New Jersey</td>
<td>3600</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td><strong>Onshore</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2012 - 500 MW Northern Ohio</td>
<td>1300</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>2012 - 500 MW Chicago Area</td>
<td>1400</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>2012 - 500 MW Cincinnati Area</td>
<td>1300</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>2012 - 500 MW Eastern PA</td>
<td>1400</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>2012 - 500 MW Southern NJ</td>
<td>1000</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>2012 - 500 MW Virginia</td>
<td>1200</td>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>

Health and climate benefits of offshore wind facilities in the Mid-Atlantic United States.
Carbon price of $10/ton in implementation year (modeled as 2016)

Additional $5/ton added per year, until plateau price of $40/ton (modeled as 2023)
Cumulative Health Benefits of the MA Carbon Fee from 2017-2040

<table>
<thead>
<tr>
<th>Health Benefit</th>
<th>Central Estimate (95% Confidence Interval)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lives Saved</td>
<td>340 (82 - 59)</td>
</tr>
<tr>
<td>Respiratory Hospitalizations Avoided</td>
<td>26 (14 - 39)</td>
</tr>
<tr>
<td>Cardiovascular Hospitalizations Avoided</td>
<td>28 (19 - 36)</td>
</tr>
<tr>
<td>Heart Attacks Avoided</td>
<td>20 (12 - 28)</td>
</tr>
<tr>
<td>Value of Health Benefits (undiscounted)</td>
<td>$2.9 billion ($0.66 - $5.2 billion)</td>
</tr>
<tr>
<td>Value of Health Benefits (discounted at 3% per year)</td>
<td>$2.0 billion ($0.48 - $3.5 billion)</td>
</tr>
</tbody>
</table>

Assumes implementation in 2017
Lives Saved per Year

- **Central Estimate**
- **Low Estimate**
- **High Estimate**

Range based on 95% Confidence Interval from Epidemiology
Lives Saved per Year By Source and Fuel

- Residential Oil
- Commercial Oil
- Industrial Oil
- Industrial Coal
- Transport Distillate Fuel Oil
- Non-road other
- Residential Natural Gas
- Commercial Natural Gas
- Industrial Natural Gas
- Motor Gasoline
- Transport Residual Fuel Oil

Mainly Transportation – Gasoline and Diesel
Mainly Heating Buildings
Lives Saved per Year Exposed Pollutant Type

- PM2.5
- Ozone
Value of Health Benefits per Year, undiscounted

<table>
<thead>
<tr>
<th>Year</th>
<th>Central Estimate</th>
<th>Low Estimate</th>
<th>High Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>2014</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>2017</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>2020</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>2023</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>2026</td>
<td>$150</td>
<td>$150</td>
<td>$150</td>
</tr>
<tr>
<td>2029</td>
<td>$150</td>
<td>$150</td>
<td>$150</td>
</tr>
<tr>
<td>2032</td>
<td>$150</td>
<td>$150</td>
<td>$150</td>
</tr>
<tr>
<td>2035</td>
<td>$150</td>
<td>$150</td>
<td>$150</td>
</tr>
<tr>
<td>2038</td>
<td>$150</td>
<td>$150</td>
<td>$150</td>
</tr>
</tbody>
</table>

Range based on 95% Confidence Interval from Epidemiology
Summary and Conclusions

- Carbon fee can have substantial co-benefits for health by reducing air pollutants

- These will tend to occur to those living and working near sources (mainly roadways)

- The benefits to air quality and health will occur basically immediately after emissions reductions begin

- Health benefits are important part of decisions about how to reduce carbon emissions
Changing the energy system

Climate Change

Air Quality and Health
Changing the energy system
Full cost accounting for the life cycle of coal

Paul R. Epstein,¹ Jonathan J. Buonocore,² Kevin Eckerle,³ Michael Hendryx,⁴ Benjamin M. Stout III,⁵ Richard Heinberg,⁶ Richard W. Clapp,⁷ Beverly May,⁸ Nancy L. Reinhart,⁸ Melissa M. Ahern,⁹ Samir K. Doshi,¹⁰ and Leslie Glustrom¹¹
<table>
<thead>
<tr>
<th>Type</th>
<th>low</th>
<th>best</th>
<th>high</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate, Direct CO2 Emissions</td>
<td>$20.6</td>
<td>$61.8</td>
<td>$205.6</td>
</tr>
<tr>
<td>Methane emissions from mine</td>
<td>$0.7</td>
<td>$2.1</td>
<td>$6.8</td>
</tr>
<tr>
<td>Land Disturbance</td>
<td>$0.05</td>
<td>$0.16</td>
<td>$3.35</td>
</tr>
<tr>
<td>Direct Black Carbon Emissions</td>
<td>$0.012</td>
<td>$0.045</td>
<td>$0.21</td>
</tr>
<tr>
<td>Air Quality, Direct Emissions</td>
<td>$65.1</td>
<td>$187.5</td>
<td>$187.5</td>
</tr>
<tr>
<td>Mercury, lost productivity</td>
<td>$0.125</td>
<td>$1.625</td>
<td>$8.13</td>
</tr>
<tr>
<td>Mercury, mental retardation</td>
<td>$0.044</td>
<td>$0.36</td>
<td>$3.25</td>
</tr>
<tr>
<td>Mercury, CV disease</td>
<td>$0.25</td>
<td>$3.54</td>
<td>$17.94</td>
</tr>
<tr>
<td>Fatalities in the public due to coal transport</td>
<td>$1.81</td>
<td>$1.81</td>
<td>$1.81</td>
</tr>
<tr>
<td>Public health burden of communities in Appalachia</td>
<td>$74.6</td>
<td>$74.6</td>
<td>$74.6</td>
</tr>
<tr>
<td>Subsidies – Environmental Law Institute Estimate 2007</td>
<td>$5.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subsidies – Energy Information Administration Estimate 2007</td>
<td>$3.2</td>
<td>$3.2</td>
<td></td>
</tr>
<tr>
<td>Abandoned Mine Lands</td>
<td>$8.8</td>
<td>$8.8</td>
<td>$8.8</td>
</tr>
<tr>
<td>Total</td>
<td>$175.2</td>
<td>$345.3</td>
<td>$523.3</td>
</tr>
</tbody>
</table>
Epstein et al. 2011
Coal = ~4 ¢/kWh (~5 ¢/kWh with scrubbers)
Coal with cleaner combustion ~ 15¢/kWh (CCS is extra 2-5 ¢/kWh)
Onshore Wind = 4-8 ¢/kWh
Offshore Wind = 10-20 ¢/kWh
Solar PV = 6-25 ¢/kWh (lower for rooftop)
2014 U.S. Residential Price = 12.5 ¢/kWh

Epstein et al. 2011

U.S. EIA
Carlyle, Saskatchewan

Sept. 7, 2017
Comparing coal to natural gas, natural gas power plants emit half as many greenhouse gas emissions.[7]

Besides the appeal of a low-cost domestic fuel source, natural gas power plants can be constructed in as little as 20 months for approximately one third the levelized capital cost for a typical coal plant.[21] Natural gas electricity generation relies on three basic technologies:

Smithsonianian.com

Natural Gas Really Is Better Than Coal
If too much methane leaks during production, though, the benefits will be lost

eia
Independent Statistics & Analysis
U.S. Energy Information Administration

How much carbon dioxide is produced when different fuels are burned?

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Carbon Dioxide (g/lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal (anthracite)</td>
<td>228.6</td>
</tr>
<tr>
<td>Coal (bituminous)</td>
<td>205.7</td>
</tr>
<tr>
<td>Coal (lignite)</td>
<td>215.4</td>
</tr>
<tr>
<td>Coal (subbituminous)</td>
<td>214.3</td>
</tr>
<tr>
<td>Diesel fuel and heating oil</td>
<td>161.3</td>
</tr>
<tr>
<td>Gasoline (without ethanol)</td>
<td>157.2</td>
</tr>
<tr>
<td>Propane</td>
<td>139.0</td>
</tr>
<tr>
<td>Natural gas</td>
<td>117.0</td>
</tr>
</tbody>
</table>

Health is nowhere in this debate, and it should be.
Clean Power Plan Argument Hinges on Health Benefits

President Obama’s pitch for the pollution fighting measure relies on saving lives

E.P.A. Carbon Emissions Plan Could Save Thousands of Lives, Study Finds
WASHINGTON - New carbon emissions standards that were proposed last year for coal-fired power plants in the United States would substantially improve human health and prevent more than 3,000 premature deaths per year, according to a new study.

Scientists: EPA’s curbs on coal-burning will save thousands of lives
The Obama administration’s proposed curbs on coal-burning power plants could prevent thousands of deaths each year from heart attack and respiratory disease, scientists said Monday in the first peer-reviewed study to examine the measure’s health impacts.

Peer-reviewed, non-partisan academic study finds that the EPA emissions rule will save thousands of lives
The EPA’s new rules limiting carbon emissions from coal-fired power plants will not, on their own, solve climate change. They will not kill coal country, either. What they will do, once they’re finalized later this summer and implemented, is reduce air pollution.
Driven by health

Full cost accounting for the life cycle of coal

Paul R. Epstein, 1 Jonathan J. Buonocore, 2 Kevin Eckerle, 3 Michael Hendryx, 4 Benjamin M. Stout III, 5 Richard Heinberg, 6 Richard W. Clapp, 7 Beverly May, 8 Nancy L. Reinhart, 9 Melissa M. Ahern, 9 Samir K. Doshi, 10 and Leslie Gustrom 11
Apply the same holistic approach to ask: “Is natural gas really that much better than coal for health?”
Nearly 1 in 5 wells have same vulnerability as the well that blow out in Aliso Canyon, CA.
Drone for measuring air pollution from natural gas
Acknowledgements

- Merck Family Fund
- Clean Water Fund
- Ms. Louise Hara & Mr. Wayne Davis
- Mrs. Susanna B. Place & Mr. Scott L. Stoll
- Tara Greco and the Dante R. Greco Trust
- Ms. Cynthia Margaret Iris & Mr. Richard McFadyen
- Mr. Nagesh Mahanthappa
- Mr. John M. Dacey
- Dr. James Recht & Nina Dillon
- Zaurie Zimmer & Craig LeClair
- Dr. Richard Clapp
- Dr. Susan J. Ringler
- Ms. Bonni J. Widdoes