Global Carbon Budget

Total Regional Carbon Emissions & Percentage of Global Emissions

2012 (MT CO₂)

North America: 6,643, 18.5%
South America: 1,401, 4.0%
Europe: 556, 16.0%
Asia: 17,160, 49.3%
Middle East: 2,458, 7.1%
Africa: 1,313, 3.8%
Oceania: 444, 1.3%

Combustion CO₂ Emissions Factors by Fuel (µg/MJ)

Natural Gas: 50.3
Gasoline Without Ethanol: 67.5
Diesel Fuel and Heating Oil: 69.3
Coal (Bituminous): 88.4
Coal (Subbituminous): 92.1
Coal (Lignite): 92.5
Coal (Anthracite): 98.2

Source: Global Carbon Atlas Website, CO₂ emissions as of 2012

Source: Environmental Information Administration
Share of Natural Gas in Total Energy-related Emissions of Major Air Pollutants and CO₂

- **Particulate matter**: 31Mt
- **Sulphur dioxide**: 79Mt
- **Nitrogen oxides**: 108Mt
- **Carbon dioxide**: 32Gt

Legend: Gas, Coal, Oil, Bioenergy, Non-combustion

Source: IEA World Energy Outlook, 2017
Non-GHG Emission Factors

Global Average Emissions Factors and Share of Major Pollutant Emissions by Fuel, 2015

Note: Global average emission factors calculate across all types of sectoral activity and all types of technology. Fuels not shown are considered negligible.

Methane Emissions

Global Anthropogenic GHG Budget (MtCO)

- Carbon Dioxide 76%
- Methane 16%
- Nitrogen Oxides 6%
- FGas 2%

Source: World Resources International

Anthropogenic Methane Emissions by Source (Mt)

- Enteric Fermentation & Manure 31%
- Gas, Oil & Industry 23%
- Landfills & Waste 17%
- Coal Mining 12%
- Rice Cultivation 9%
- Biomass Burning 5%
- Biofuel Burning 3%
- Fossil Fuels 121 Mt
- Agriculture & Waste 195 Mt
- Biomass & Biofuel 30 Mt

## Reliable Partner for a Secure and Sustainable Generation Mix

Illustrative framework for evaluating investment options by Risk source, Magnitude, and Time Scale

<table>
<thead>
<tr>
<th>Risk Source</th>
<th>Immediate (0-2 yrs)</th>
<th>Short (2-5 yrs)</th>
<th>Medium (5 - 20 yrs)</th>
<th>Long (20 - 50 yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Supply</td>
<td>![Diagram]</td>
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<td>![Diagram]</td>
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<tr>
<td>Fuel Transportation</td>
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<tr>
<td>Fuel price volatility and generating costs</td>
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<td>Environmental Regulations</td>
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<td>Cost-Competitiveness</td>
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<td>State and Federal Incentives</td>
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<tr>
<td>Resource Variabilities and Dispatchability</td>
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<td>![Diagram]</td>
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<tr>
<td>Transmission planning and costs</td>
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<td>![Diagram]</td>
</tr>
</tbody>
</table>

### A Hypothetical NG Project

### A Hypothetical RE Project

**Volume of Risk**

- Negligible
- Some
- Considerable
- Extensive

*NG = Natural Gas  RE = Renewable Energy

**Source:** Adapted from National Renewable Energy Laboratory, 'Opportunities for Synergies between Natural Gas and Renewable Energy in the Electric Power and Transportation Sector' (December 2012)
Responsive, Flexible, and Clean Electricity Generation Resource

Comparison of as-published life cycle GHG Emission estimates for Electricity Generation Technologies

*Avoided Emissions, no Removal of GHG's from the Atmosphere*

<table>
<thead>
<tr>
<th>Technology</th>
<th>Count of Estimates</th>
<th>Count of References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biopower</td>
<td>222 (+4)</td>
<td>52 (+0)</td>
</tr>
<tr>
<td>Photovoltaics</td>
<td>124</td>
<td>26</td>
</tr>
<tr>
<td>Concentrating Solar Power</td>
<td>42</td>
<td>13</td>
</tr>
<tr>
<td>Geothermal Energy</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Hydropower</td>
<td>28</td>
<td>11</td>
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<tr>
<td>Ocean Energy</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Wind Energy</td>
<td>126</td>
<td>49</td>
</tr>
<tr>
<td>Nuclear Energy</td>
<td>125</td>
<td>32</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>83 (+7)</td>
<td>36 (+4)</td>
</tr>
<tr>
<td>Oil</td>
<td>24</td>
<td>10</td>
</tr>
<tr>
<td>Coal</td>
<td>169 (+12)</td>
<td>50 (+10)</td>
</tr>
</tbody>
</table>

Note: The impacts of the land use changes are excluded from this analysis. Here, natural gas refers only to conventional sources.
Source: National Renewable Energy Laboratory, 2012
Reliable Partner for a Secure & Sustainable Generation Mix

Ramping Rate (% of full load per minute)

- Simple Cycle Gas Turbine: 20%
- Hydro Reservoir: 15%
- Bioenergy: 8%
- Combined Cycle Gas Turbine: 8%
- Steam Plants (gas, oil): 7%
- Coal Power: 6%
- Concentrated Solar Power: 6%
- Geothermal: 5%
- Lignite: 4%
- Nuclear: 2%

Start-up Time from Cold to Hot (hours)

- Hydro Reservoir: 0.1
- Simple Cycle Gas Turbine: 0.16
- Geothermal: 1.5
- Combined Cycle Gas Turbine: 2
- Concentrated Solar Power: 2.5
- Coal Power: 3
- Bioenergy: 3
- Lignite: 6
- Nuclear: 24

Minimum Load Requirements (percent)

- Hydro Reservoir: 5%
- Geothermal: 15%
- Simple Cycle Gas Turbine: 15%
- Combined Cycle Gas Turbine: 20%
- Concentrated Solar Power: 25%
- Coal Power: 30%
- Steam Plants (Gas, Oil): 30%
- Nuclear: 50%
- Lignite: 50%
- Bioenergy: 50%

Responsive, flexible, and clean electricity generation resource

### SOx [g/MWh]
- Natural Gas: 0.08
- Biomass: 3.02
- Liquid Fuels: 128.8
- Brown Coal: 229.6
- Hard Coal: 229.6

### PM2.5 [g/MWh]
- Natural Gas: 0.25
- Brown Coal: 2.52
- Hard Coal: 2.52
- Liquid Fuels: 9.2

### NOx [g/MWh]
- Natural Gas: 24.9
- Liquid Fuels: 50.4
- Biomass: 59
- Brown Coal: 86.8
- Hard Coal: 100.8

### Mercury (mg/MWh)
- Natural Gas: 0.03
- Liquid Fuels: 0.38
- Biomass: 0.42
- Brown Coal: 0.45
- Hard Coal: 0.98

### CO (g/MWh)
- Liquid Fuels: 4.2
- Natural Gas: 11
- Brown Coal: 31.6
- Hard Coal: 42
- Biomass: 72

### CO₂ (kg/MWh)
- Gas (CCGT IEA Data\(^*)\): 350
- Gas Avg: 515
- Oil: 759
- Coal: 1,020

**Notes:** Taken into account the efficiency of transforming thermal energy into electricity, a combined cycle gas turbine (CCGT) emits well under half of CO₂/KWh than a coal plant.

**Sources:**
1. PM, Mercury, CO, NOx factors data: Air Pollution Emission Factor Library; Emission Factors EMEP/EEA Guidebook (Accessed: August 2017)
2. CO₂ data: Commission for Environmental Cooperation, 2011, North American Power Plant
3. \(^*)\text{CCGT Data from IEA World Energy Outlook 2017}
Clean Fuel for Road Transport

Well-to-Wheel GHG Intensity: Passenger Vehicles (g CO₂eq/km)

- Petrol: 168.7, 22.5%
- Diesel: 140.4, 6.9%
- CNG: 130.7
- CNG (10% biocng, 10% sng): 108
- Biocng: 30

Well-to-Wheel GHG Intensity: Heavy-Duty Vehicles (g CO₂eq/km)

- Diesel (FQD): 1074
- HPDI (LNG): 912, -15%
- SI (LNG): 1005, -6%
- SI (CNG): 908, -16%

Notes:
CNG: Compressed Natural Gas  SNG: Synthetic Natural Gas  FQD: EU Fuel Quality Directive. Emissions Assessed: CO₂, CH₄, and N₂O and aggregated into 1 emissions indicator in CO₂ equivalents. CO₂-eq is calculated using Global Warming Potential factors of the 4th IPCC Assessment Report for a 100-year timeframe (GWP 100).

Clean Fuel for Road Transport: Air Pollution

Switching older fleet vehicles to new CNG vehicles would result in significant air quality benefits. The values below demonstrate pollutant reductions from replacing 2007 vehicles with new CNG cars. (Based on 2012 analysis)

CNG vs GASOLINE

- Light Duty Vehicle: 34% NOx reduction
- School Bus: 76% NOx reduction
- Light Duty Truck: 91% NOx reduction
- Heavy Duty Truck: 88% NOx reduction

Ship GHG Emissions by Fuel (g CO₂ eq/kWh)

- HFO (JEC-WtW): 742.1 g CO₂ eq/kWh
- MDO ("FQD"): 749.6 g CO₂ eq/kWh
- LNG (Dual Fuel 4 Stroke Engine): 661.6 g CO₂ eq/kWh
- LNG (Dual Fuel 2 Stroke Engine, HP): 588.8 g CO₂ eq/kWh

WtT: Well to Tank
TtW: Tank to Wake
WtW: Well to Wake

Notes:
- The use of Marine Diesel Oil (MDO) as pilot fuel was assumed in both cases.
- The dual-fuel (4-stroke) engine uses gaseous Natural Gas according to the Otto Cycle together with a small quantity of pilot fuel for ignition.
- The dual-fuel (2-stroke) engine also uses a small amount of pilot fuel besides Natural Gas, which is injected at high pressure.
- For the tank-to-wake data, the CO₂ emissions were modelled based on primary data for 85% load. The assessment of this study neglects the effect of implementing an additional exhaust gas after-treatment (e.g. by a scrubber).
- MDO WtW emissions are chosen to be the same as those reported for diesel in the documents related to the Fuel Quality Directive (FQD), Council Directive (EU) 2015/652.
- HFO direct CO₂ emissions from the combustion process as well as the emissions from the HFO supply are used as provided in the JEC- WtW study.

Source: NGVA Europe, 2017, Greenhouse Gas Intensity of Natural Gas (link here)
Marine Fuel for Clean Air at Sea

Ship Pollutant Emissions by Fuel g/MJ

Note: 1. The sulphur content in the fuel (weight %) is assumed to be 1% for the Heavy Fuel Oil, 0.1% for the Marine Distillate Oil and approximately 0% for the LNG fuel.

Clean & Efficient Heating Fuel

SOx Emissions Rate (µg/MJ)

- Natural Gas
- Woodchip
- Propane
- Oil

PM10 Emissions Rate (µg/MJ)

- Propane
- Natural Gas
- Oil
- Woodchip

92% Efficiency

Extraction, Processing & Transportation (7% ENERGY LOSS)

Source Energy = 106 GJ

Generation

No energy conversion necessary, therefore no energy is lost

Distribution (1% ENERGY LOSS)

Delivered to Customer

CO Emissions Rate (µg/MJ)

- Propane
- Oil
- Natural Gas
- Woodchip

NOx Emissions Rate (µg/MJ)

- Natural Gas
- Oil
- Propane
- Woodchip

Note: Emissions were given on a heat basis. The data shown are based on tests of various types of boilers and boiler fuels.

Source: "Lifecycle Impacts of Heating with Wood in Scenarios Ranging from Home and Institutional Heating to Community Scale District Heating Emissions" (Dovetail Partners Inc. 2012)
Particulate Matter (PM)

- **PM<sub>2.5</sub>**
  - Combustion particles, organic compounds, metals, etc.
  - <2.5 µm (microns) in diameter

- **PM<sub>10</sub>**
  - Dust, pollen, mold, etc.
  - <10 µm (microns) in diameter

- **HUMAN HAIR**
  - 50-70 µm (microns) in diameter

- **FINE BEACH SAND**
  - 90 µm (microns) in diameter

Source: Graphic from EPA
Household Emissions from Cooking Fuels

**Avg. CO Emissions Factors (µg/MJ) Log Scale**

- Natural Gas: 9,500 (x105)
- Coal Gas: 1,000,000
- Kerosene: 1,100,000
- Biomass (Dung): 10,300,000

**Avg. PM Emissions Factor (µg/MJ) Log Scale**

- Natural Gas: 5,500 (x146)
- Coal Gas: 5,500
- Kerosene: 10,000
- Biomass (Dung): 800,000

**Note:**
The chart data are based on emission factors for household stoves for laboratory or simulated kitchen measurements using the Water Boiling Test (WBT).
The stoves used for testing natural gas, dung (biomass) and coal gas fall under the improved unvented stove category while kerosene falls under the traditional unvented stove category.

**Sources:**
World Energy Outlook Special Report 2016, Energy and Air Pollution
Comparing Emissions of Cooking Fuel Choices in China

Comparison of Air Emissions from Cooking Fuel in China (g/MJ of delivered heat)

- **PM**
  - Firewood: 1.49
  - Crop Residue: 3.4
  - Biomass Pellets: 0.21
  - LPG: 0.68
  - Kerosene: 0.87
  - Natural Gas (Di-methyl ether): 0.057
  - DME: 0.75
  - Coal Mix: 1.18
  - Electricity: 1.81

- **SO₂**
  - Firewood: 0.29
  - Crop Residue: 0.3
  - Biomass Pellets: 0.39
  - LPG: 0.2
  - Kerosene: 0.23
  - Natural Gas (Di-methyl ether): 0.17
  - DME: 0.75
  - Coal Mix: 1.81
  - Electricity: 1.33

**Notes:**
LCA compared the environmental footprint of current and possible fuels used for cooking in China.
Results are presented based on delivered cooking energy, covering production, processing, distribution and use for each fuel system.
*Since electricity generation in China is dominated by coal, the electricity impacts are influenced by coal production and combustion impacts.*

Deaths Attributable to Household and Outdoor Air Pollution

Natural Gas is a clean burning fuel and does not produce toxic PM emissions, which are one of four leading causes of premature deaths in the world.

Household 4.3 million

- China 34%
- Africa 15%
- Rest of World 9%
- Other Developing Asia 8%
- Indonesia 4%
- EU 1%
- NAM 0.3%

Outdoor 3.0 million

- China 35%
- India 21%
- Rest of World 16%
- Africa 10%
- Other Developing Asia 9%
- Russia 5%
- Indo 2%
- EU 1%

NAM – North America  
EU – European Union  
INDO – Indonesia

Source: Graphic from IEA
Health Impact of Particulate Matter Emissions

Deaths from ambient PM 2.5 pollution (in thousands)

Source: OECD Report, ‘The economic consequences of outdoor air pollution: Policy highlights’ (June 2016); Primary energy consumption changes calculated based on data from EEA (EU) and EIA (US).
Nearly Half of the World’s Population Relies on Solid Fuels as Primary Energy for Cooking & Heating at Home


Europe: 5% of the population
Western Pacific: 40% of the population
Americas: 9% of the population
South East Asia: 63% of the population
Eastern Mediterranean: 29% of the population
Africa: 79% of the population

Share of Global Population Without Access to Clean Energy at Home

ACCESS 59%
NO ACCESS 41%

“Every year, 3.5 million premature deaths are caused by the use of solid fuels.”
~ World Health Organization

“Over 50% of global PM emissions originate from the residential sector, largely due to incomplete combustion of solid fuels.”
~ International Energy Association

Notes: Solid fuels: Biomass fuels, such as wood, charcoal, crops or other agricultural waste, dung, shrubs and straw, and coal
Source: WHO, Global Health Observatory Data Repository, ‘Population using solid fuel (estimates) by Region’ (Updated January 2015)