How Green Will Electricity be When Electric Vehicles Arrive?

Edward S. Rubin

Department of Engineering and Public Policy
Department of Mechanical Engineering
Carnegie Mellon University

Presentation to the

SAE 2011 Government/Industry Meeting
Washington, DC

January 28, 2011
A Few Simple Questions

• How “green” is U.S. electricity today in terms of greenhouse gas (GHG) emissions?

• What has been the recent trend in power sector emissions and carbon intensity?

• What is the outlook for low-carbon electricity and plug-in hybrid electric vehicles (PHEVs) ?

• In light of the above, would adoption of PHEVs significantly reduce U.S. GHG emissions?
The Current Situation
CO$_2$ from Energy Use is the Dominant Greenhouse Gas

**U.S. Greenhouse Gas Emissions**

weighted by 100-yr Global Warming Potential (GWP)

7.4% CO$_2$  
6.5% CH$_4$  
2.2% N$_2$O  
83.9% Others

Source: USEPA, 2007

E.S. Rubin, Carnegie Mellon
Sources of CO₂ Emissions

U.S. CO₂ Emissions

- Fossil fuels supply 70% of all U.S. electricity
- Electricity + Transportation emit ~75% of all CO₂
Trend in Power Sector Carbon Dioxide Emissions

CO2 Emissions from U.S. Electric Sector

Source: Based on data from USDOE, 2010

15% increase per decade
## Power Plant Carbon Intensity

**(CO₂ emissions per net kilowatt-hour)**

<table>
<thead>
<tr>
<th>Power Plant Fuel and Type</th>
<th>Direct Emissions (g CO₂/ kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal (existing sub-critical)</td>
<td>1000</td>
</tr>
<tr>
<td>Coal (new super-critical)</td>
<td>800</td>
</tr>
<tr>
<td>Natural Gas (turbines)</td>
<td>800</td>
</tr>
<tr>
<td>Natural Gas (comb. cycle)</td>
<td>400</td>
</tr>
<tr>
<td>Nuclear</td>
<td>0</td>
</tr>
<tr>
<td>Hydro</td>
<td>0</td>
</tr>
<tr>
<td>Wind</td>
<td>0</td>
</tr>
</tbody>
</table>

**Average emission rate based on U.S. 2008 fuel mix = 0.59 t CO₂ / MWh**

*Source: Samaras, 2008; Rubin, 2000*
Carbon Intensity of Electric Power Sector Has Been Decreasing

3.8% reduction per decade since 1989

7.5% / decade since 2000

Source: Based on data from USDOE, 2010
## Upstream Activities Increase Life-Cycle Emissions

<table>
<thead>
<tr>
<th>Plant Type</th>
<th>Direct GHGs (g CO₂ / kWh)</th>
<th>Upstream GHGs (g CO₂-eq/ kWh)</th>
<th>Total life cycle GHGs (g CO₂-eq/ kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal (new)</td>
<td>800</td>
<td>50</td>
<td>850</td>
</tr>
<tr>
<td>NGCC (new)</td>
<td>400</td>
<td>75</td>
<td>475</td>
</tr>
<tr>
<td>Coal w/ CCS</td>
<td>100</td>
<td>50</td>
<td>150</td>
</tr>
<tr>
<td>NGCC w/ CCS</td>
<td>50</td>
<td>75</td>
<td>125</td>
</tr>
<tr>
<td>Solar (PV)</td>
<td>0</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Wind</td>
<td>0</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Nuclear</td>
<td>0</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Hydro</td>
<td>0</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

*Source: Samaras, 2008*
# Low-Carbon Options

At recent rates of decarbonization, getting to 100 g CO₂ / kWh (direct) would take ~ 100 – 200 years!

---

<table>
<thead>
<tr>
<th>Plant Type</th>
<th>Direct GHGs (g CO₂ / kWh)</th>
<th>Upstream GHGs (g CO₂-eq/ kWh)</th>
<th>Total life cycle GHGs (g CO₂-eq/ kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal (new)</td>
<td>800</td>
<td>50</td>
<td>850</td>
</tr>
<tr>
<td>NGCC (new)</td>
<td>400</td>
<td>75</td>
<td>475</td>
</tr>
<tr>
<td>Coal w/ CCS</td>
<td>100</td>
<td>50</td>
<td>150</td>
</tr>
<tr>
<td>NGCC w/ CCS</td>
<td>50</td>
<td>75</td>
<td>125</td>
</tr>
<tr>
<td>Solar (PV)</td>
<td>0</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Wind</td>
<td>0</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Nuclear</td>
<td>0</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Hydro</td>
<td>0</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

Source: Samaras, 2008
Future Outlook
Why Decarbonize?

- Future decarbonization of U.S. electricity supplies will be driven by traditional market forces (e.g., fuel prices and cost of technology), as well as by government policies at the state and federal levels (both “carrots” and “sticks”).

- Major policy drivers currently include:
  - State-level renewable portfolio standards
  - Federal incentives for low-carbon technologies
  - State or regional C-caps and air pollutant limits
  - State & federal regulatory commission actions (can help or impede decarbonization)
Current State-level Renewable Portfolio Standards

RPS Policies
(As of January 2011)

29 states + DC and PR have an RPS
(7 states have goals)

Source: www.dsireusa.org, 2011
Reference Case: 
Current policies only

Source: DOE/EIA, 2011

E.S. Rubin, Carnegie Mellon
Carbon Intensity of Electric Grid Continues to Fall Gradually

Source: Natl Acad, 2010
Energy-related CO₂ Emissions Continue to Increase

(AEO 2011 Reference Case)

Source: DOE/EIA, 2011

18% increase from 2009 to 2035
Policy Cases:
PHEVs and Low-Carbon Power
Recent Studies of Interest


Estimates of PHEV Deployment Vary Widely Across Studies

<table>
<thead>
<tr>
<th>Study</th>
<th>2020</th>
<th>2030</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>min</td>
<td>base</td>
<td>max</td>
</tr>
<tr>
<td>Samaras, 2008</td>
<td>0.8</td>
<td>4.1</td>
<td>8.9</td>
</tr>
<tr>
<td>EPRI, 2009</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NAS, 2010</td>
<td>1.8</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

million PHEVs on the road in given year
EPRI studies
Year 2010 comparison of GHG emissions when PHEV 20 is charged entirely with electricity from specific power plant technologies (EPRI/NRDC)

Source: EPRI/NRDC, 2007
Year 2050 comparison of GHG emissions when PHEV 20 is charged entirely with electricity from specific power plant technologies (EPRI/NRDC)

Source: EPRI/NRDC, 2007
EPRI 2009 MERGE Analysis of Power System Response to CO$_2$ Limits

(2050 GHG emissions limit = 83% below 2005 levels)

*Limited portfolio excludes CCS, new nuclear, and PHEVs

Source: EPRI, 2009
Low-Carbon Power Achievable but Limited Portfolio Raises Power Cost

Source: EPRI, 2009
EPRI/NRDC Carbon Intensity Scenarios for the Power Sector

Source: EPRI/NRDC, 2007

Requires much faster decarbonization than business-as-usual

E.S. Rubin, Carnegie Mellon
Year 2050 comparison of vehicle GHG emissions for High, Medium, and Low electric sector CO$_2$ intensity with PHEVs 10, 20, 40 (EPRI/NRDC)

Source: EPRI/NRDC, 2007
National Academies study
GHG Emission Rates from Future Electric Grid—Two Scenarios

Source: NAS, 2010
GHG Emissions from Light-Duty Fleet for NAS Cases

Source: NAS, 2010

E.S. Rubin, Carnegie Mellon
GHG Emissions from PHEVs Compared to Advanced ICE/HEVs

Source: NAS, 2010
Samaras (CMU) study
Potential Annual Power Demand from PHEV Adoption

Potential Annual Demand from PHEVs (GWh)

- High PHEV adoption
- Baseline PHEV adoption
- Low PHEV adoption

EIA AEO: Total U.S. non-hydro renewable generation in 2030 ~ 160,000 GWh
Total U.S. non-hydro renewable generation in 2007 ~ 103,000 GWh

Source: Samaras, 2008
Power Sources for Battery Charging Vary by Region, Season and Time of Day

Source: Samaras, 2008
Conclusions

• Low-carbon electricity is key to achieving large GHG reductions with PHEVs. New policy drivers will be needed to accelerate the pace of decarbonizing the U.S. grid.

• Even with low-C electricity, GHG reductions compared to conventional hybrid vehicles will be small unless PHEV batteries with extended ranges are commercially viable.

• Achieving large GHG reductions with PHEVs also will require advanced integration and planning of power system capacity and transmission since the marginal fuels used to charge batteries will vary by region, season and time of day.
Thank You

rubin@cmu.edu