Deep Decarbonization

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Global Fossil CO₂ Emissions

- 1990-2010: Approximately Flat
- 1995-2000: +3.1%/yr
- 2000-2010: +1.0%/yr
- 2010-2018: 2018: 37.1 Gt CO₂, +2.7% (1.8%-3.7%/yr)

350 Chicago
DePaul University
November 11, 2019
CO₂ Concentration in the Atmosphere Correlates with Global Temperature Rise

Svante Arrhenius
1859-1927
1896 CO₂ causes global warming “cutting edge 19th century science”

http://www.climatecentral.org/gallery/graphics/co2-and-rising-global-temperatures
Global Carbon Emissions Seemed to be Peaking . . . But Are Now Rising

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http://www.globalcarbonproject.org/carbonbudget/18/presentation.htm
2018's Billion Dollar Disasters in Context

Adam B. Smith, NOAA
February 7, 2019
We Are Not on a Path to < 2°C Global Temperature Rise

< 2°C temperature rise requires full decarbonization by 2060-2080 and negative emissions thereafter

More Like 3°C or 4°C

Scenario group
Baseline (3–5.1°C)
6.0 W/m² (3.2–3.3°C)
4.5 W/m² (2.5–2.7°C)
3.4 W/m² (2.1–2.3°C)
2.6 W/m² (1.7–1.8°C)
How Big is 2°C?

The last ice age was 4.5°C colder
Sea level rise 120 m

Earth 18,000 years ago

http://www.lakepowell.net/sciencecenter/paleoclimate.htm
Recent Climate Change Reports

21st Conference of Parties
Paris, November 2015
Must decarbonize by 2050

IPCC SR15.
October 2018
Limit warming to 1.5°C
Above pre-industrial levels

US Global Change Research Program
Congressionally mandated
November 2018
Climate changing faster than expected
Possible “Tipping Points”

*Collapse of major ice sheets in Greenland and Antarctica:* reflecting white ice replaced by absorbing dark water triggers runaway warming, loss of ice, dramatic changes in sea level and ocean circulation.

*Disruption of thermohaline circulation:*
  - Transfer of heat from equator to poles interrupted
  - Transfer of CO\(_2\) from shallow to deep ocean interrupted

Onset of new climate regime

*Sudden release of methane from arctic permafrost or undersea methane clathrates:* Runaway increase in rate of warming

*Ocean uptake of carbon:* acidification of the oceans could kill photosynthesizing plankton, that remove CO\(_2\) from the air. Shells of marine organisms might begin to dissolve, releasing carbon back into the environment.

https://scied.ucar.edu/longcontent/predictions-future-global-climate
How Fast are We Decarbonizing?


https://cfpub.epa.gov/ghgdata/inventoryexplorer/#allsectors/allgas/econsect/all
Climate Change is Accelerating

How Scientists Got Climate Change So Wrong
Few thought it would arrive so quickly. Now we’re facing consequences once viewed as fringe scenarios.
Eugene Linden  Fri Nov 8, 2019 New York Times

Scientists triple their estimates of the number of people threatened by rising seas
150 million could live below the high tide line by 2050, new research finds.
Washington Post Oct 29, 2019


Note: The I.P.C.C.’s 2007 estimate of future sea level rise did not include satellite data on the contribution of melt water from Greenland and Antarctica because of disagreements among scientists.
Source: E. Linden, How Scientists Got Climate Change So Wrong, NYT Nov 8, 2019
Public Awareness of Climate Change

24% ... believe that half of climate scientists, or fewer, think human-caused global warming is happening.

36% ... believe that between 51 and 90 percent of scientists think global warming is happening.

17% ... correctly understand that almost all climate scientists think global warming is happening.

21% Don’t know

Source: Yale Program on Climate Change Communication survey conducted in April; figures do not add up to 100 percent because of rounding

Increased support for prioritizing policies on the environment, climate change since 2011

% U.S. adults who say ____ should be a top priority for the president and Congress

A majority of U.S. adults say climate change affects their local area; 31% say it affects them personally

% of U.S. adults who say the effects of global climate change are ...

40% Affecting their local community not too much/not at all

31% Affecting them personally

28% Not affecting them personally

59% Affecting their local community a great deal or some

1% Refused

*In 2014 and earlier, respondents were asked about dealing with “global warming.” In 2015 half the sample was asked about either “global warming” or “global climate change”; 34% called “global climate change” a top priority while 38% said this about “global warming.”

Source: Survey of U.S. adults conducted Jan. 9-14, 2019

“Public’s 2019 Priorities: Economy, Health Care, Education and Security All Near Top of List”

PEW RESEARCH CENTER
After Paris 2015:
Focus on 100% reduction after 2050, and negative emissions after 2080
40 year life of natural gas turbines is a negative legacy compared to renewables
Electric vehicles transforming transportation became thinkable

Conversation shifted from the first 50% to the last 50%
How to decarbonize long haul air, trucking and sea transportation?
What about space and water heating, industrial processes that use combustion of fossil fuel for heat
Do we have the technology, or do we need new technology?
Electric Vehicle Challenges

• Greater range  
  > 400 miles not 250 miles

• Faster charging  
  minutes not hours

• Lower purchase price  
  $20K not $50K

• Longer battery lifetime  
  16 years not 8 years

• Greater safety  
  greater danger from EV battery fires

• Recycling  
  to meet EV demand for resources

• Less temperature sensitivity  
  lose 40% of range in Minneapolis winter

All of These Challenges are Battery
Electric Vehicles - High or Low Cost?

Electric Vehicles

Fewer Moving Parts
Engine + Transmission
Electric Motor

Hundreds
One

Lower Maintenance Cost

Lower Fuel Cost

Higher Efficiency
25% >90%

Gasoline / mile   Electricity / mile
$0.08 - $0.12   $0.04 - $0.06

EVs are the economic choice for high mileage vehicles

Average maintenance cost for NYC municipal vehicles in 2018

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<th>Model</th>
<th>Gas Cost</th>
<th>Hybrid Cost</th>
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<td>$1805 gas</td>
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</tr>
</tbody>
</table>

NYC Department of Citywide Administrative Services;
Chart: Andrew Witherspoon/Axios
https://www.axios.com/electric-vehicle-maintenance-newyorkcity-fb1c2704-14dd-4026-a0d1-0d82f5b6d19.html

Electric Vehicle Battery Cost:
Barrier to Entry, Benefit for High Mileage and Fleet Use

Fleet vehicles switch to electric – high impact on sales and grid

Amazon will order 100,000 electric delivery vans from EV startup Rivian, delivery 2021-2024
https://www.theverge.com/2019/9/19/20873947/amazon-electric-delivery-van-rivian-jeff-bezos-order
Beyond EVs – Electric Buses and Long Haul Trucks

Cost of battery packs for trucks
$500/kWh (2013) → $200/kWh (2019)
Electric trucks are heavier than diesel trucks
Energy density of lithium ion batteries << diesel fuel
→ Recharging en route → delays
Hydrogen Fuel Cell Trucks

- Long range, fast refueling
- 50-60% efficiency
- No emissions
- Still need to lower cost

Hydrogen fuel cell

Hydrogen + oxygen $\rightarrow$ electricity, water and heat
Two Routes to All-Electric Flight

Scale up prototype all-electric air taxis

Boeing’s first autonomous air taxi flight ends in fewer than 60 seconds. Jan 19, 2019

Eviation Aircraft “Alice” https://www.eviation.co/alice/
9 passengers, 650 mile range, 275 mph, 10 000-30 000 ft, Li-ion 900kWh, propellers on tail and wingtips, $4M
Planes bought by Cape Air, Barnstable MA, for short hop coastal flights

Electrify existing full size plane

Hybrid-electric aircraft
Airbus E Fan X
The future is electric

Paris Air Show
Le Bourget, Paris, June 17-23, 2019
Decarbonizing the Electricity Grid

Mega-trends shaping the grid

Energy storage

Renewable wind and solar

Decarbonization

Electric cars, buses and trucks

Distributed energy resources

Smart energy management

Two way flow

Storage is central to all the mega-trends

Critical Outcomes

Decarbonization – 100% by 2050?

Reliability

US

214 outage minutes/year

EU

~50 outage minutes/year

Resilience

How fast to restore power?

Time or cost metric?

Cyber-security

A hack-proof grid

Cost

US

12.7 c/kWh

EU

26.6 c/kWh

Can we achieve critical outcomes with present technology?

Yes

Policy, regulation, and business plan innovation

No

Where are the gaps?

R&D funding priorities
Charging Electric Vehicles

EVs could increase electricity demand by 20% - 38% in 2050

First significant increase in demand since 2000
Integrates transportation and the electricity grid into a single universal energy system
Frees transportation from dependence on foreign oil
Path to decarbonize transportation along with electricity grid

How to meet additional demand?
• Charge off peak to avoid building new generation capacity
Off-peak capacity is typically idle gas peaker plants → Significantly greater carbon emissions than renewable charging

Solution: Charge EVs only with renewable electricity
Replace gas peaker plants with storage

Renewable+Storage falling faster than either alone

No fuel cost: Floor depends only on technology cost

Storage alone competitive with gas peaker plants

Solar+Storage < $0.03/kWh=$30/MWh in NV and AZ: the economic choice
>$0.02/kWh in Los Angeles (7-1-19)

”+Storage” moving beyond first adopters

Source: BloombergNEF. Note: The global benchmark is a country-weighted average using the latest annual capacity additions. The storage LCOE is reflective of a utility-scale Li-ion battery storage system running at a daily cycle and includes charging costs assumed to be 60% of whole sale base power price in each country.
Electric Heating of Commercial and Residential Buildings

Technology exists

Policy incentives needed

Berkeley, California: ban on natural gas pipes in many new buildings starting January 1, 2020
Decarbonizing Industry

Industry uses fossil fuels in two ways
Feedstocks for plastics and other high value products
Combustion for high process temperatures for steel production

Electricity cannot produce the high temperatures needed for industry – requires combustion

Hydrogen as a combustion fuel?

76% comes from reforming natural gas
22% from coal gasification
2% from electrolysis

Electricity costs more than natural gas per unit energy, and less energy is required to convert natural gas to hydrogen than to electrolyze water

→ R&D to decrease cost of producing hydrogen by electrolysis
Perspective

Deep decarbonization of the global economy is needed to avoid the worst consequences of climate change.

Some technology exists: renewable electricity, electric cars, hydrogen fuel cells, hydrogen combustion.

Policy is needed to promote deployment of existing technology.

R&D is needed to promote new technology for energy storage and electrolysis of water to hydrogen.

We are not yet on track to achieve deep decarbonization of the economy by 2050.