Amory B. Lovins
Cofounder and Chief Scientist

Stanford 2015 Climate and Energy Project
Research Symposium
Stanford University, 13 October 2015
The rise and fall of the U.S. whaling industry
The rise and fall of the U.S. whaling industry

Lamp retrofits from whale oil to coal oil gain market traction, become common.

Drake strikes oil in Pennsylvania.

Consumption of whale oil + sperm oil in American market (1,000 US gallons).

What if the biggest threats weren’t on the radar?
Intensity decrease has had $31 \times$ the impact of renewable growth.

- **1975–2014 savings from intensity reduction:** 2,089 qBTU
- **1975–2014 growth in total renewable output:** 67 qBTU
Who’s the competition?

Rex Tillerson
Chairman and CEO, ExxonMobil

Ali bin Ibrahim al-Naimi
Saudi oil minister

Pål Kibsgård
CEO, Schlumberger Ltd.
Who’s the competition?

Elon Musk, Tesla, SolarCity, SpaceX

Sebastian Thrun, Google’s self-driving car

Anna Jaffe, Mobi

Lee Eng Lock, efficiency engineer

Robin Chase, Zipcar, GoLoco, Buzzcar

Michael Brylawski, VisionFleet

Peter Calthorpe, architect

Ferdinand Piëch, Volkswagen (ret.)
“I can’t wait to see what happens when our industries merge.”
If a problem can’t be solved, **enlarge it.**

—attributed to Dwight Eisenhower
Volume Production of Electrified Carbon-Fiber Cars

**Hypercar Revolution 5-seat hybrid SUV**
- 2000 virtual design (RMI with two Tier Ones)
- 67 mpg (gasoline) or 114 mpge (H₂), 1,887 lb (−53%)
- 3.6 L/100 km (gasoline) or 2.1 (H₂), 857 kg (−53%)

**VW XL1 2-seat plug-in hybrid**
- 2014 low-volume production
- 235 mpge, 1,759 lb
- 0.9 L/100 km, 798 kg

**Toyota 1/X 4-seat plug-in hybrid**
- 2007 concept car
- 131 mpge, 926 lb (−70%)
- 1.8 L/100 km, 420 kg (−70%)

**BMW i3 4-seat battery-electric hatchback**
- 2013– midvolume production, $41–45k
- 124 mpg, 185+-mile range-extender option
- 1.9 L/100 km, 300+-km range-extender option
Batteries’ Costs Continue to Plummet

$/kWh

2012 $/kWh

Tesla announcement


GTM research
US Energy Information Administration
Average expert projection
Navigant, Bloomberg New Energy Finance
Tripled-Efficiency Trucks and Planes
Enabled by IT, multiple transportation methods provide a seamless, cheaper, more pleasant user experience.
Autonomous vehicles: from PIGS to SEALs
From PIGS to SEALS
Transportation problems in China
From disorganized chaos to smooth travel experience
From superblock to walking distance

Graphics courtesy of Peter Calthorpe
Transportation Without Oil
despite 90% more automobility, 118% more trucking, 61% more flying

“We must leave oil before it leaves us.”

Fatih Birol
Chief Economist
Executive Director
International Energy Agency 2008
U.S. natural gas prices, 1985–2015: official forecasts vs. reality
Heresy Happens

U.S. energy intensity

Index of U.S. Primary Energy Per Dollar of Real GDP

Government and Industry Forecasts, 1975

Actual

Lovins, *Foreign Affairs*, Fall 1976

Reinventing Fire, 2011

0
0.25
0.5
0.75
1
1.25
1975
1990
2005
2020
2035
2050
Lovins House, Old Snowmass, Colorado (1983)
U.S. buildings: 3–4× energy productivity worth 4× its cost 
(site energy intensities in kWh/m²-y; U.S. office median ~293)

~277 → 173 (−38%)  
2010 retrofit

284 → 85 (−70%)  
2013 retrofit

... → 108 (−63%)  
2010–11 new

... → ≤50 (−83% to −85%)  
2015 new
80% energy savings in Hyderabad office, lower capex

Infosys DSB1 (2009): world’s largest side-by-side HVAC experiment
Radiant side (11,152 m²): 66 kWh/m²-y (–80%), capex –9%

Courtesy of Peter Rumsey PE FASHRAE (Senior Advisor, RMI) and Rohan Parikh (Infosys, Bangalore)
Radical Efficiency

motors, pumps, and pipes
Less Capital Investment

smaller equipment
Power Plant: -70%
Power Grid: -9%
Motor/Drivetrain: -12%
Pump/Throttle: -55%
Pipe: -20%
Delivered flow: 5%

100 Energy units
radically efficient industrial redesign
Netherlands: community connection
Utility revenues

- Flexible demand
- Customer preferences
- Distributed renewables
- New financial and business models
- Integrative design
- Efficiency
- Regulatory shifts
- Storage (including EVs)
Integrative design

Efficiency

Utility revenues
Australia national electricity market
Actual vs. forecast operational electricity demand

Annual electricity use (TWh)

Historical

GDP


200 220 240 260

0.8 1 1.2 1.4 1.6 1.8

Source: M. Liebreich, keynote, Bloomberg New Energy Finance summit, April 2015; 2014–15
Australia national electricity market

Actual vs. forecast electricity demand

Annual electricity use (TWh) vs. real GDP (2011 Australian Dollars)

Historical vs. 2010

GDP
Australia national electricity market

Actual vs. forecast electricity demand

Annual electricity use (TWh)

real GDP (2011 Australian Dollars)
Australia national electricity market

Actual vs. forecast electricity demand

Annual electricity use (TWh)


0.8 1 1.2 1.4 1.6 1.8

real GDP (2011 Australian Dollars)

GDP

Historical

2010 2011
Australia national electricity market

Actual vs. forecast electricity demand
Australia national electricity market

Actual vs. forecast electricity demand

[Graph showing historical and forecast electricity demand trends from 2004 to 2024, with lines for GDP and Historical data, and a y-axis for real GDP (2011 Australian Dollars) and an x-axis for years from 2004 to 2024.]
Australia national electricity market

Actual vs. forecast electricity demand

Annual electricity use (TWh)

GDP

Historical

real GDP (2011 Australian Dollars)
Australia national electricity market

Actual vs. forecast electricity demand

- Annual electricity use (TWh)
- Real GDP (2011 Australian Dollars)

Graph showing the comparison between actual and forecasted electricity demand and GDP over the years 2004 to 2024.
Australia national electricity market

Actual vs. forecast electricity demand

Annual electricity use (TWh)

real GDP (2011 Australian Dollars)
Australia national electricity market

**Actual vs. forecast electricity demand**

**Annual electricity use (TWh)**

- GDP
- Historical

**Real GDP (2011 Australian Dollars)**

- 2004: 0.8
- 2006: 1.0
- 2008: 1.2
- 2010: 1.4
- 2012: 1.6
- 2014: 1.8

Australia national electricity market

Actual vs. forecast electricity demand

Annual electricity use (TWh)

GDP

Historical

real GDP (2011 Australian Dollars)


180 190 200 210 220 230 240 250 260

0 0.8 1 1.2 1.4 1.6 1.8

2010 2011 2012 2013 2014
Australia national electricity market

Actual vs. forecast electricity demand

Annual electricity use (TWh) vs. real GDP (2011 Australian Dollars)

Historical electricity demand and GDP growth from 2004 to 2024.
Flexible demand

Utility revenues

Storage (including EVs)

Distributed renewables
Renewable Energy’s Costs Continue to Plummet

Wind and photovoltaics: U.S. generation-weighted-average Power Purchase Agreement prices, by year of signing

- Utility-scale solar PPAs
- U.S. wholesale power price
- Wind PPAs
Global power generation capacity additions, 2012–30

Source: Bloomberg New Energy Finance, redrawn from Michael Liebreich’s Summit Keynote, 7 April 2014
Variable Renewables Can Be Forecasted At Least as Accurately as Electricity Demand

French windpower output, December 2011: *forecasted one day ahead* vs. *actual*

Source: Bernard Chabot, 10 April 2013, Fig. 7, [www.renewablesinternational.net/wind-power-statistics-by-the-hour/150/505/61845/](http://www.renewablesinternational.net/wind-power-statistics-by-the-hour/150/505/61845/), data from French TSO RTE
Choreographing Variable Renewable Generation

ERCOT power pool, Texas summer week, 2050 (RMI hourly simulation)
Choreographing Variable Renewable Generation

ERCOT power pool, Texas summer week, 2050 (RMI hourly simulation)
Choreographing Variable Renewable Generation
ERCOT power pool, Texas summer week, 2050 (RMI hourly simulation)
Choreographing Variable Renewable Generation

ERCOT power pool, Texas summer week, 2050 (RMI hourly simulation)

- Solar (25 GW)
- Wind (37 GW)
- Geothermal etc.
Choreographing Variable Renewable Generation
ERCOT power pool, Texas summer week, 2050 (RMI hourly simulation)
Choreographing Variable Renewable Generation

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ERCOT power pool, Texas summer week, 2050 (RMI hourly simulation)
Choreographing Variable
Renewable Generation
Europe, 2014 renewable %
of total electricity consumed
50% Scotland

≥55% Denmark (33% wind; 2013 windpower peak 136%—55% for all December)

27% Germany (2013 peak 70%)

64% Portugal (peak 100% in 2011; 70% for the whole first half of 2013, incl. 26% wind & 34% hydro; 17% in 2005)

46% Spain (including 21% wind, 14% hydro, 5% solar)
Denmark’s transition to distributed electricity, 1980–2012

1980

- Central thermal
- Other generation
- Wind turbines

2012

Source: Risø
Utility revenues

Customer preferences
Cascading blackouts threaten security
New Jersey, United States: resilience
India: air, reliable electricity, and development
Beijing, China: air
Germany: prosperity, climate, democracy
Hawai‘i, United States: affordability and independence
Flexible demand

Utility revenues

Storage (including EVs)

Distributed renewables
Cheaper renewables *and* batteries change the game

In Westchester, NY, 60% of residential consumption in the next decade could come more cheaply from PV

Source: RMI analysis “The Economics of Load Defection,” 2015
Load control + PVs = grid optional

Uncontrolled: ~50% of solar PV production is sent to the grid, but if the utility doesn’t pay for that energy, how could customers respond?

Controlled: flexible load enables customers to consume >80% of solar PV production onsite. The utility loses nearly all its windfall and most of its ordinary revenue.

Source: RMI analysis “The Economics of Load Flexibility,” 2015
Utility revenues

Regulatory shifts

New financial and business models
How can incumbents respond to the electricity shift?
The Koch Attack on Solar Energy

By THE EDITORIAL BOARD

APRIL 26, 2014

No Free Sun for You! Why Arizona Wants to ‘Tax’ Solar Power

A new proposal would slap existing solar-paneled homeowners with a fee of up to $100 per month for the privilege of selling excess power back to the grid.

Solar Companies Sue Over New Rooftop Solar Tax In Arizona

The world's dumbest idea: Taxing solar energy

Conservative group ALEC pushes stealth tax on homeowners who install solar panels
The German example

European utilities lost $500 billion market cap in 6 years

Source: Morgan Stanley Capital International
The German example
重塑能源：中国
面向2050年能源消费和生产革命路线图研究
Value > Price > Cost
Easter Parades on Fifth Avenue, New York, 13 years apart

1900: where’s the first car?

1913: where’s the last horse?

A new and old utility

Indexed stock market price

(13 December 2012 = 1)

SolarCity

$6b market cap

Exelon

$34b market cap

12 December 2012
(SolarCity’s IPO)

May 2015
A new and old automaker

Indexed stock market price
(30 June 2010 = 1)

29 June 2010
(Tesla’s IPO)

May 2015

Tesla

General Motors

50 thousand cars per year
$30b market cap

8 million cars per year
$57b market cap
WHERE WOULD YOU INVEST YOUR MONEY?

OR
WHERE WOULD YOU INVEST YOUR MONEY?

Shell  e.on

Google  nest

SolarCity

GM  Exxon

OR

Sungevity  Tesla

RWE  Southern Company

nrgr

AEP American Electric Power  Exelon

OPower
From the Age of Carbon to the Age of Silicon
Renewables replacing $38b/y kerosene market