





# Astonishing Energy Futures

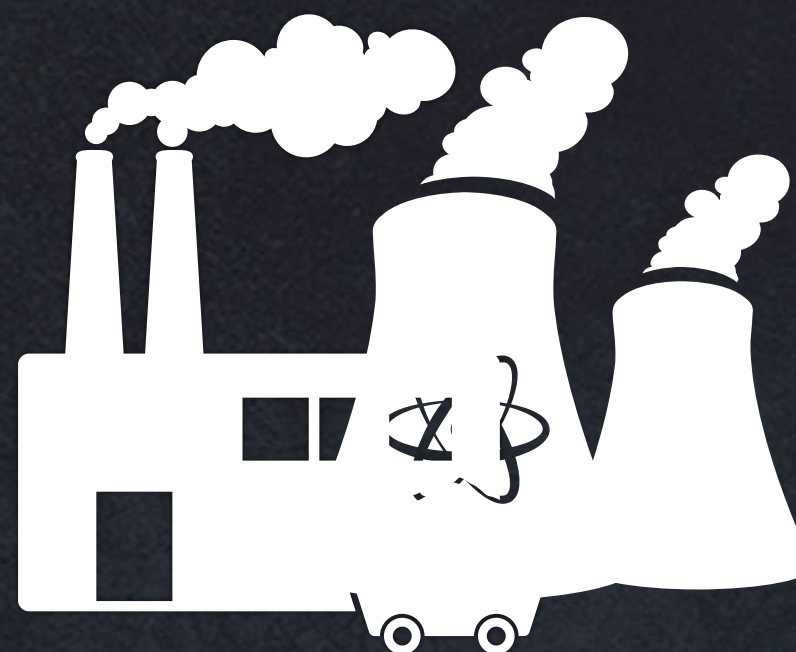
Amory B. Lovins

Cofounder and Chief Scientist

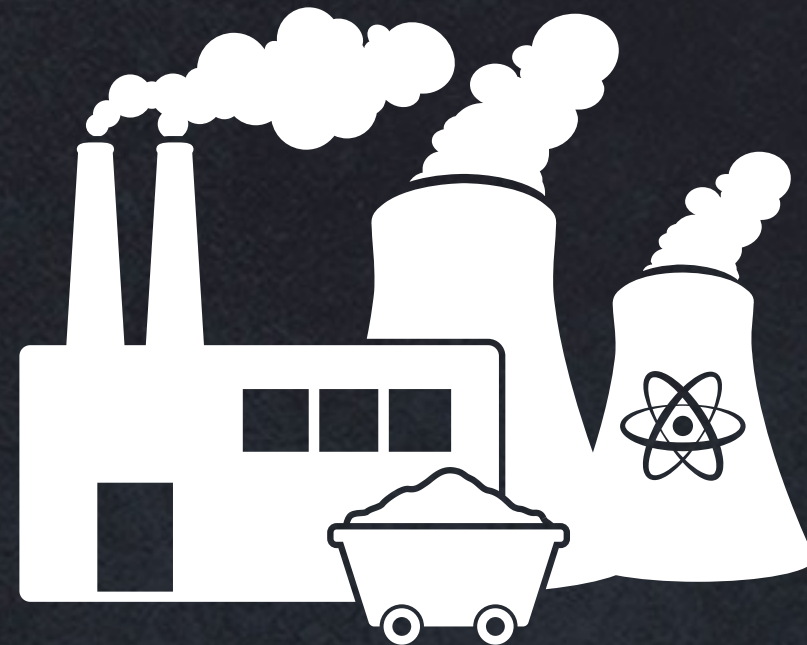
UN Economic Commission for Europe  
Committee on Sustainable Energy  
Genève (by video), 28 September 2016







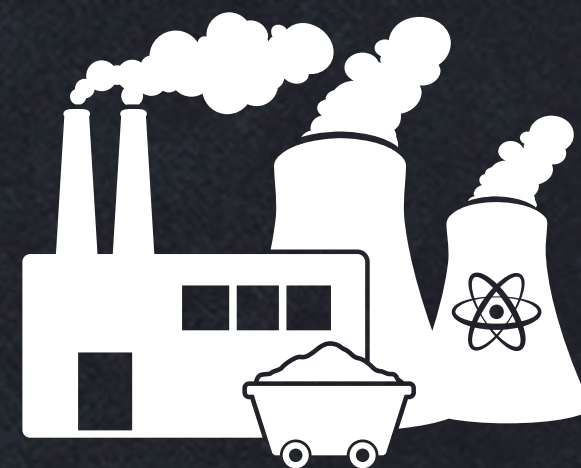




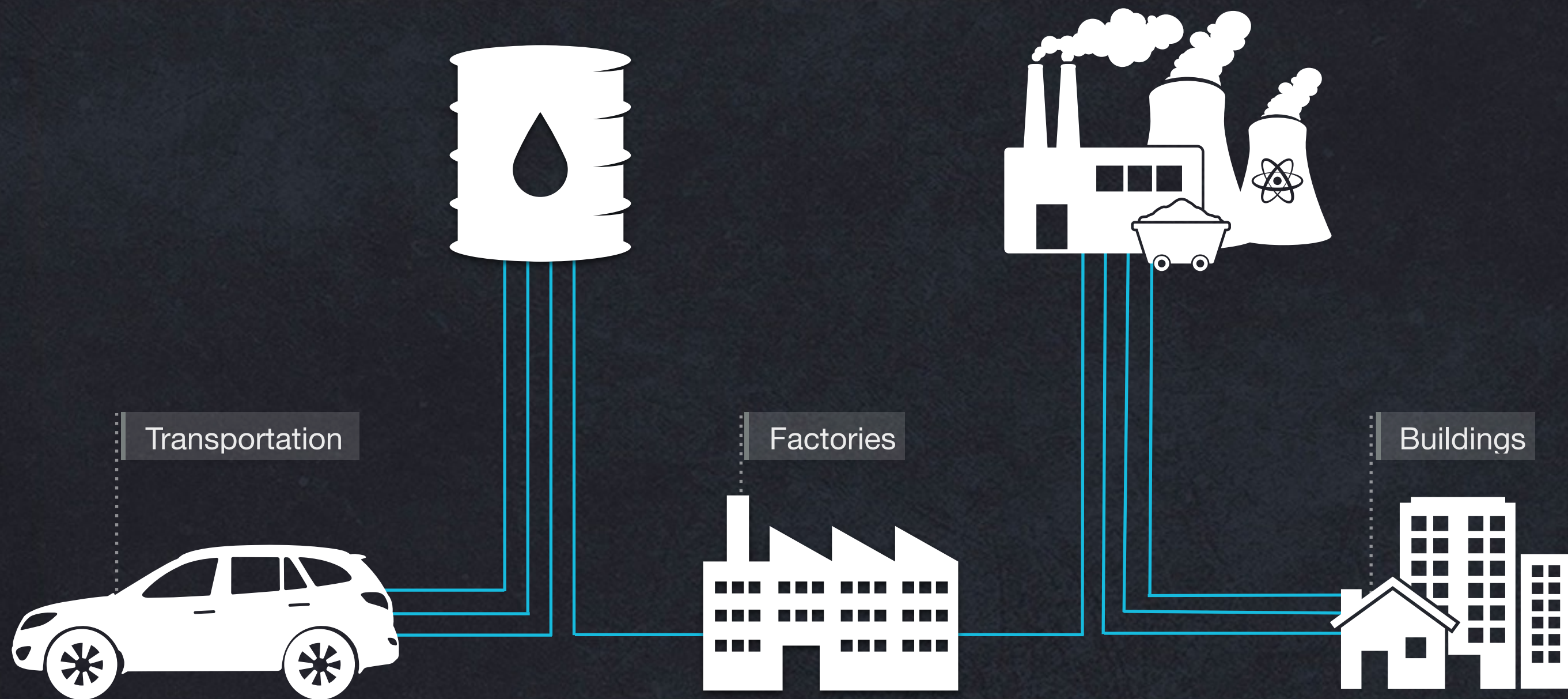
41%

40%

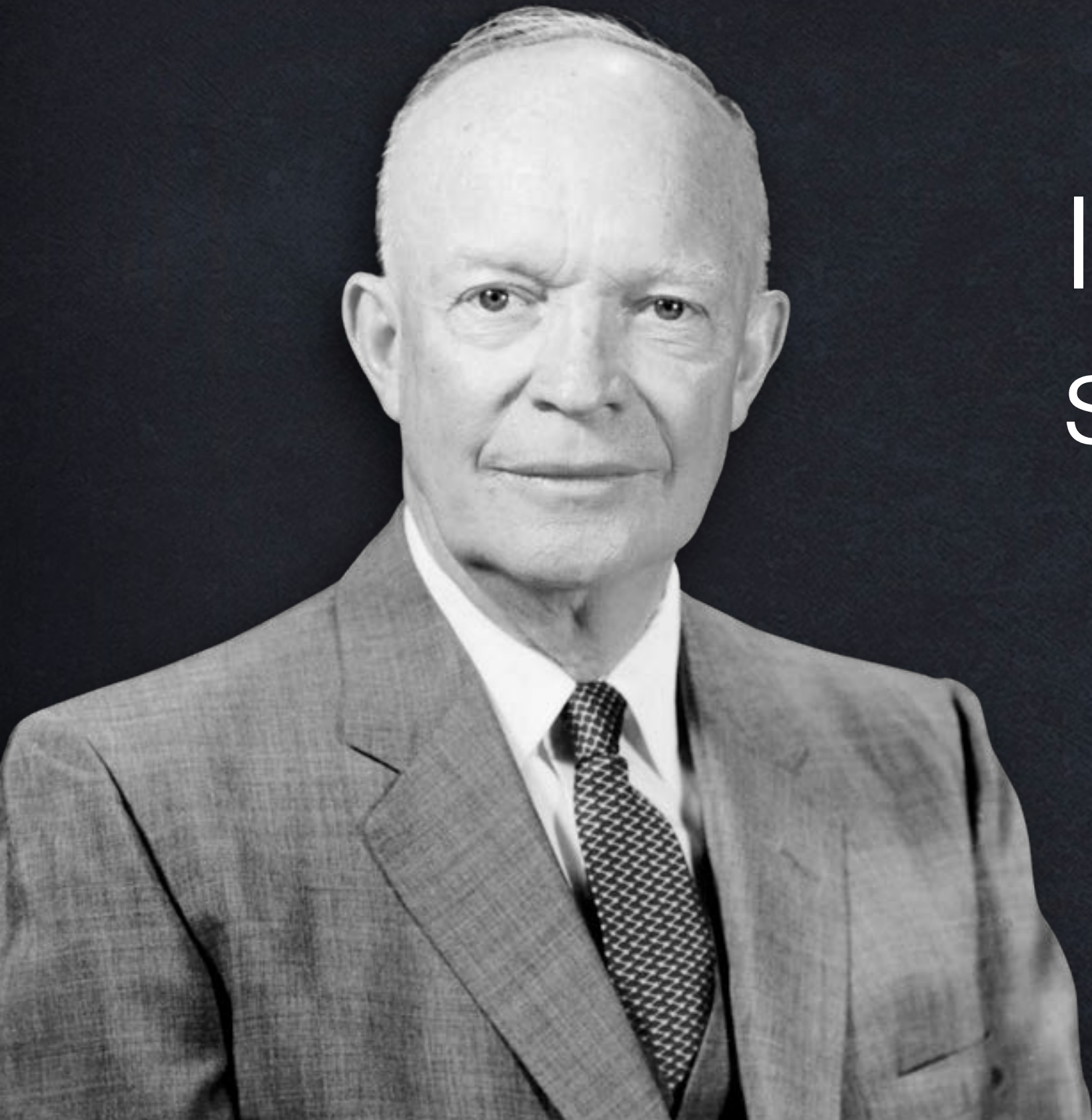








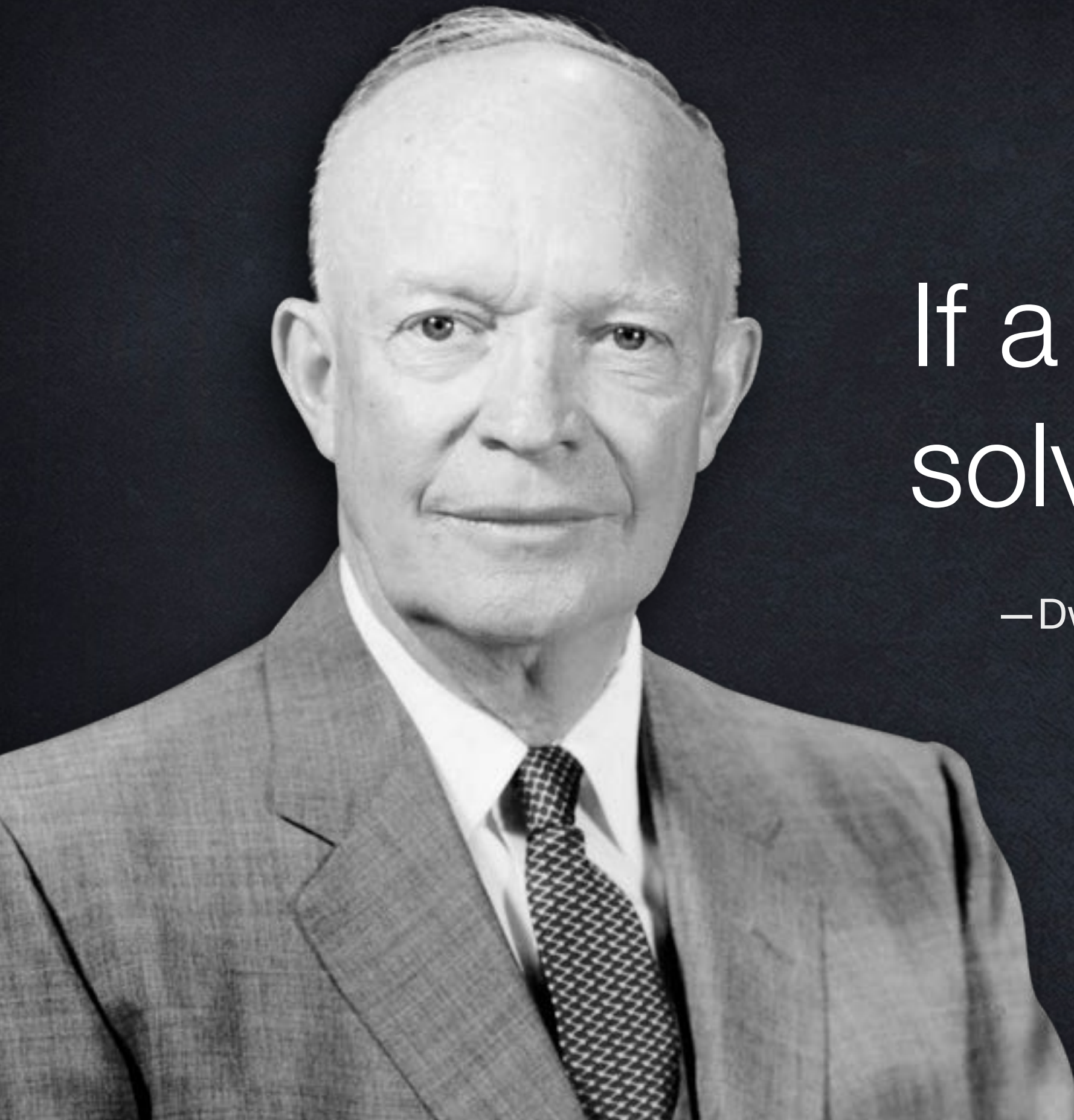




If a problem can't be  
solved, enlarge it.

—Dwight David Eisenhower





If a problem can't be  
solved, enlarge it.

—Dwight David Eisenhower



# Volume Production of Electrified Carbon-Fiber Cars



# Volume Production of Electrified Carbon-Fiber Cars



Hypercar *Revolution* 5-seat hybrid SUV  
2000 virtual design (RMI with two Tier Ones)  
3.6 L/100 km or 67 mpge (gasoline)  
2.1 L/100 km or 114 mpge (H<sub>2</sub>), 857 kg (−53%)



# Volume Production of Electrified Carbon-Fiber Cars



Hypercar *Revolution* 5-seat hybrid SUV  
2000 virtual design (RMI with two Tier Ones)  
3.6 L/100 km or 67 mpge (gasoline)  
2.1 L/100 km or 114 mpge (H<sub>2</sub>), 857 kg (–53%)



Toyota 1/X 4-seat plug-in hybrid  
2007 concept car, 420 kg (–70%)  
1.8 L/100 km or ~130 mpge



# Volume Production of Electrified Carbon-Fiber Cars



Hypercar *Revolution* 5-seat hybrid SUV  
2000 virtual design (RMI with two Tier Ones)  
3.6 L/100 km or 67 mpge (gasoline)  
2.1 L/100 km or 114 mpge (H<sub>2</sub>), 857 kg (–53%)



Toyota *1/X* 4-seat plug-in hybrid  
2007 concept car, 420 kg (–70%)  
1.8 L/100 km or ~130 mpge



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



# Volume Production of Electrified Carbon-Fiber Cars



Hypercar *Revolution* 5-seat hybrid SUV  
2000 virtual design (RMI with two Tier Ones)  
3.6 L/100 km or 67 mpge (gasoline)  
2.1 L/100 km or 114 mpge (H<sub>2</sub>), 857 kg (–53%)



Toyota *1/X* 4-seat plug-in hybrid  
2007 concept car, 420 kg (–70%)  
1.8 L/100 km or ~130 mpge



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



BMW *i3* 4-seat battery-electric hatchback  
2013– midvolume production, \$41–45k  
1.9 L/100 km or 124 mpge  
184-km range, 297 w/range-extender option



# Volume Production of Electrified Carbon-Fiber Cars



Hypercar *Revolution* 5-seat hybrid SUV  
2000 virtual design (RMI with two Tier Ones)  
3.6 L/100 km or 67 mpge (gasoline)  
2.1 L/100 km or 114 mpge (H<sub>2</sub>), 857 kg (–53%)



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



Toyota *1/X* 4-seat plug-in hybrid  
2007 concept car, 420 kg (–70%)  
1.8 L/100 km or ~130 mpge



BMW *i3* 4-seat battery-electric hatchback  
2013– midvolume production, \$41–45k  
1.9 L/100 km or 124 mpge  
184-km range, 297 w/range-extender option



# Tripled-Efficiency Trucks and Planes





# Tripled-Efficiency Trucks and Planes





Enabled by IT, multiple transportation methods provide a seamless, cheaper, more pleasant user experience

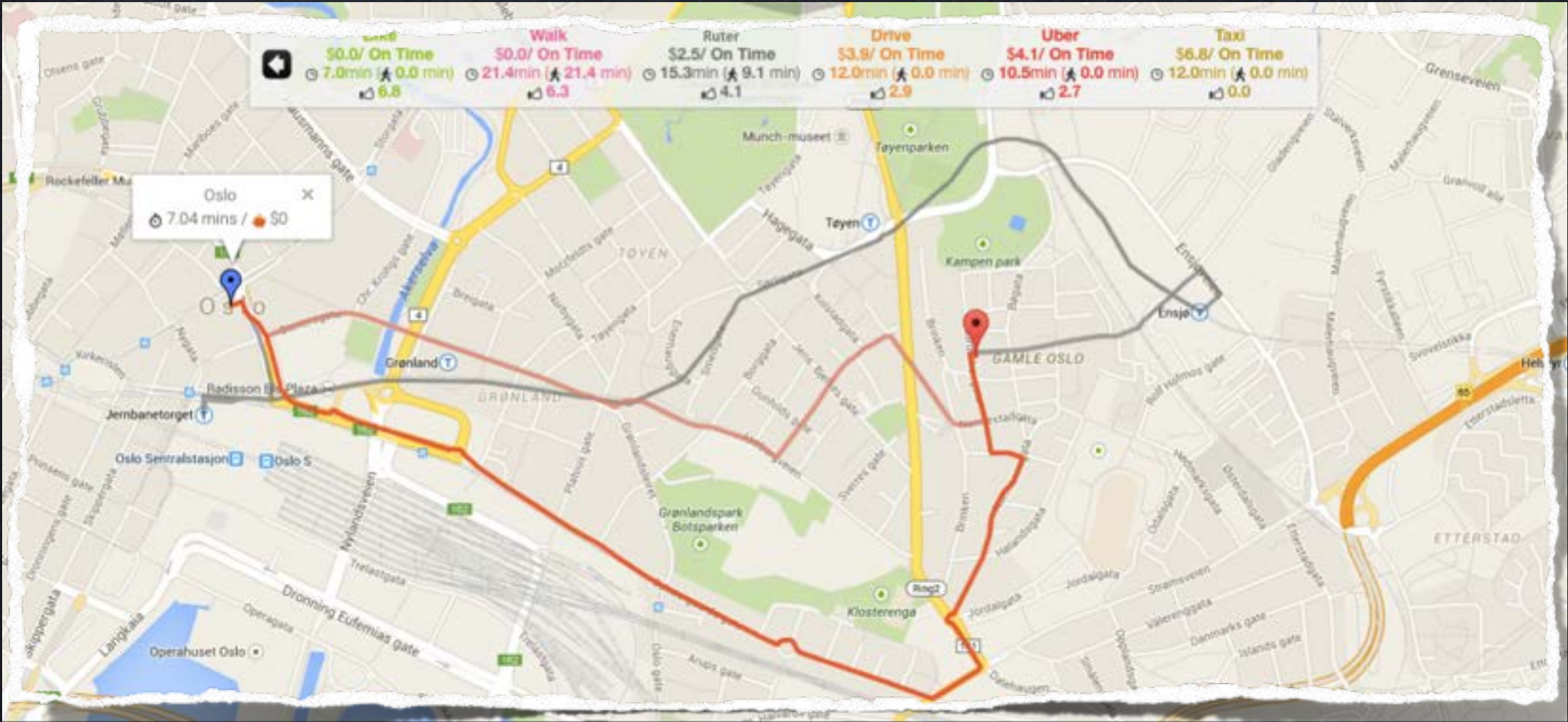


Enabled by IT, multiple transportation methods provide a seamless, cheaper, more pleasant user experience



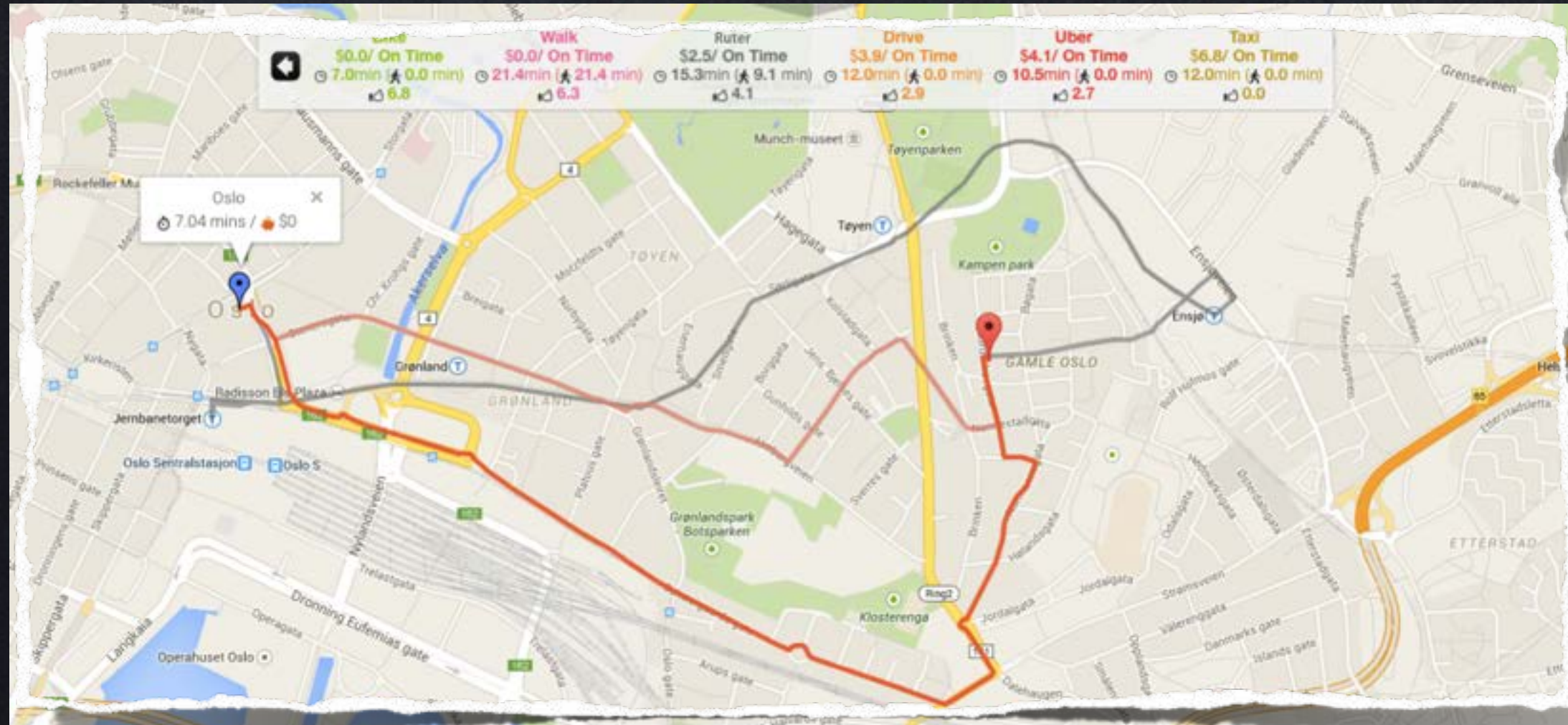


Enabled by IT, multiple transportation methods provide a seamless, cheaper, more pleasant user experience



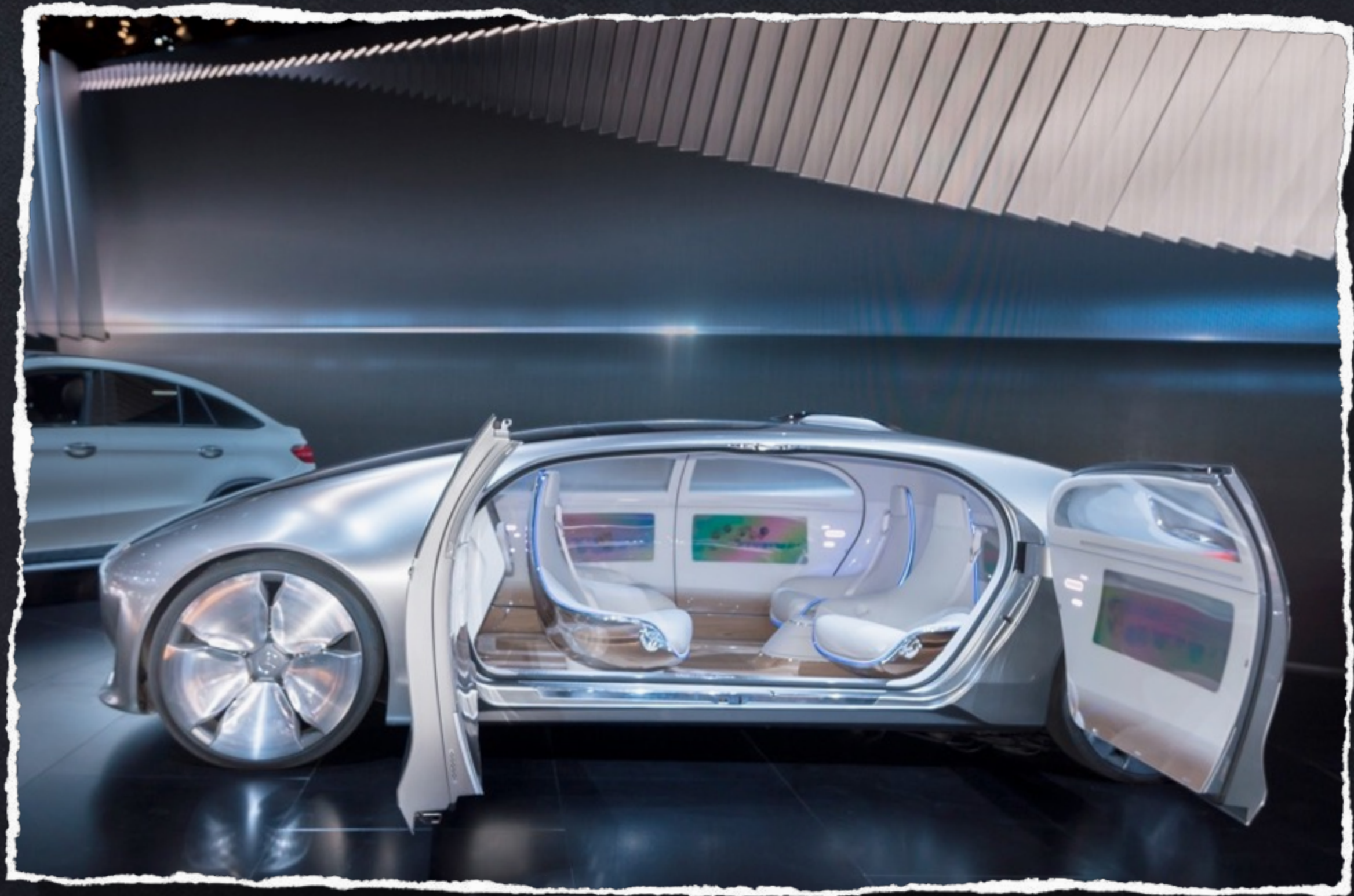


Enabled by IT, multiple transportation methods provide a seamless, cheaper, more pleasant user experience





# Autonomous vehicles: from PIGS to SEALs





# From PIGS to SEALS



**Personal Internal-combustion  
Gasoline Steel vehicles**



# From PIGS to SEALS



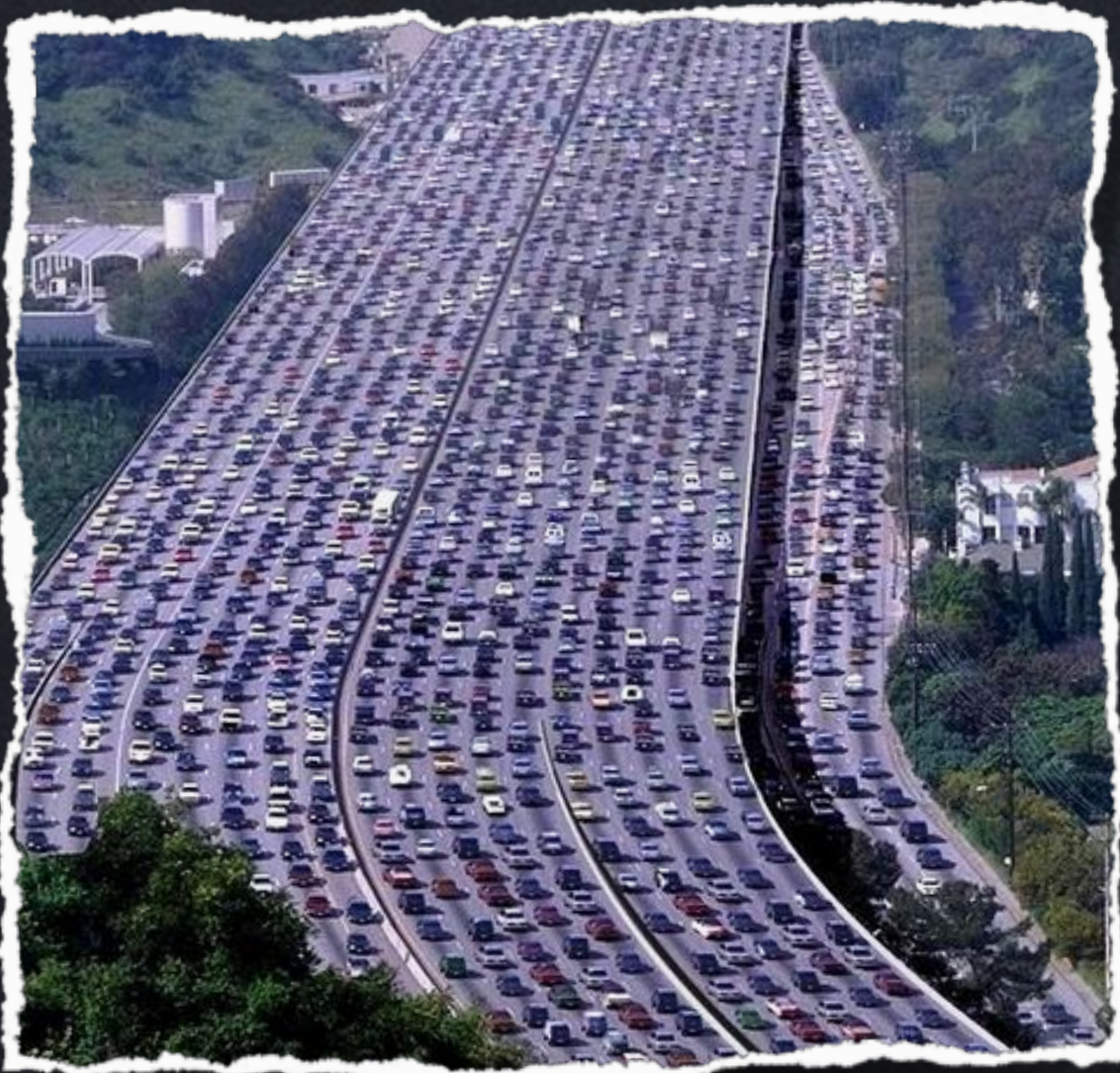
**Personal Internal-combustion  
Gasoline Steel vehicles**



**Shared Electric Autonomous  
Lightweight Service [mobility-  
as-a-service] vehicles**



# Transportation problems in China



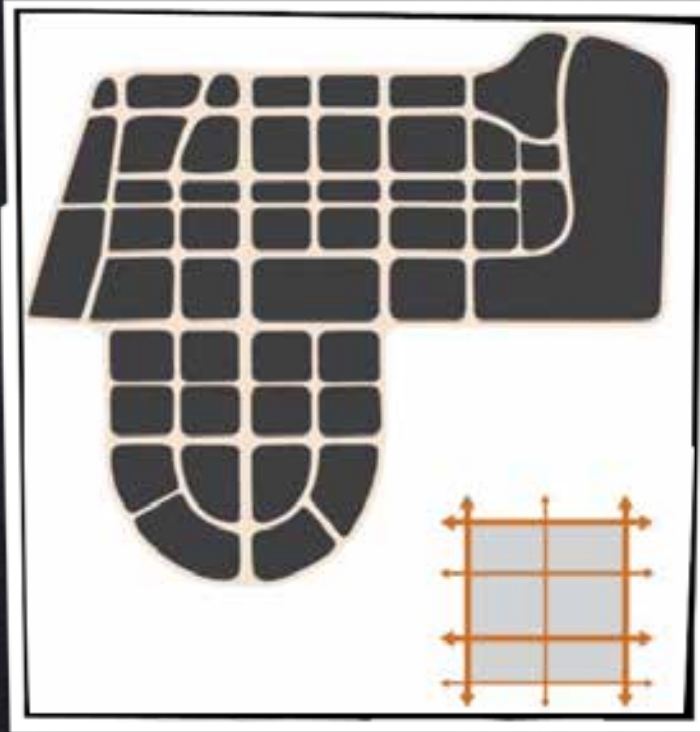


# From disorganized chaos to smooth travel experience



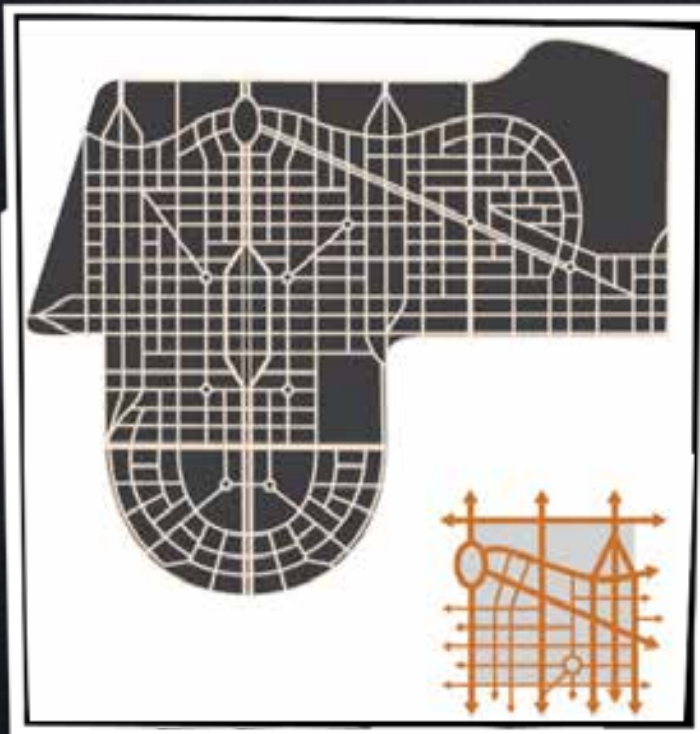
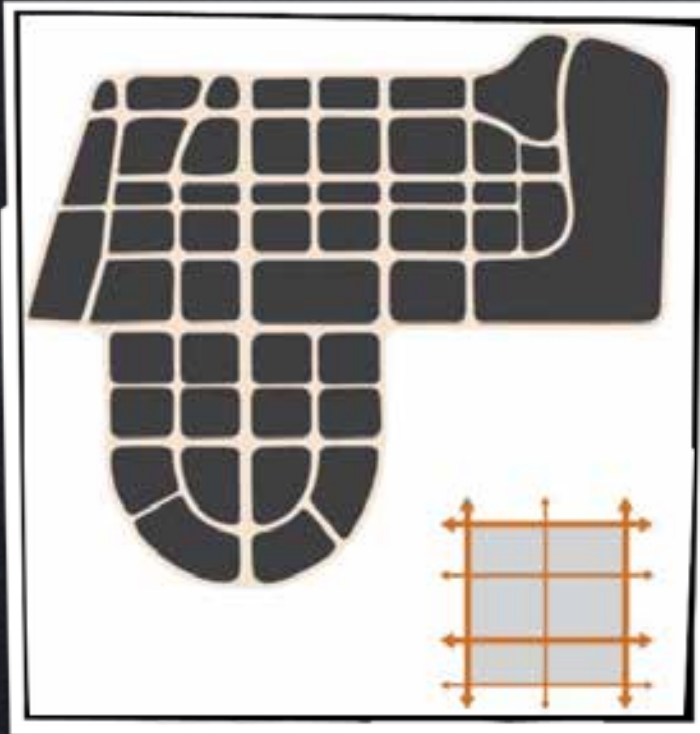


# From superblock to walking distance





# From superblock to walking distance





# Transportation Without Oil

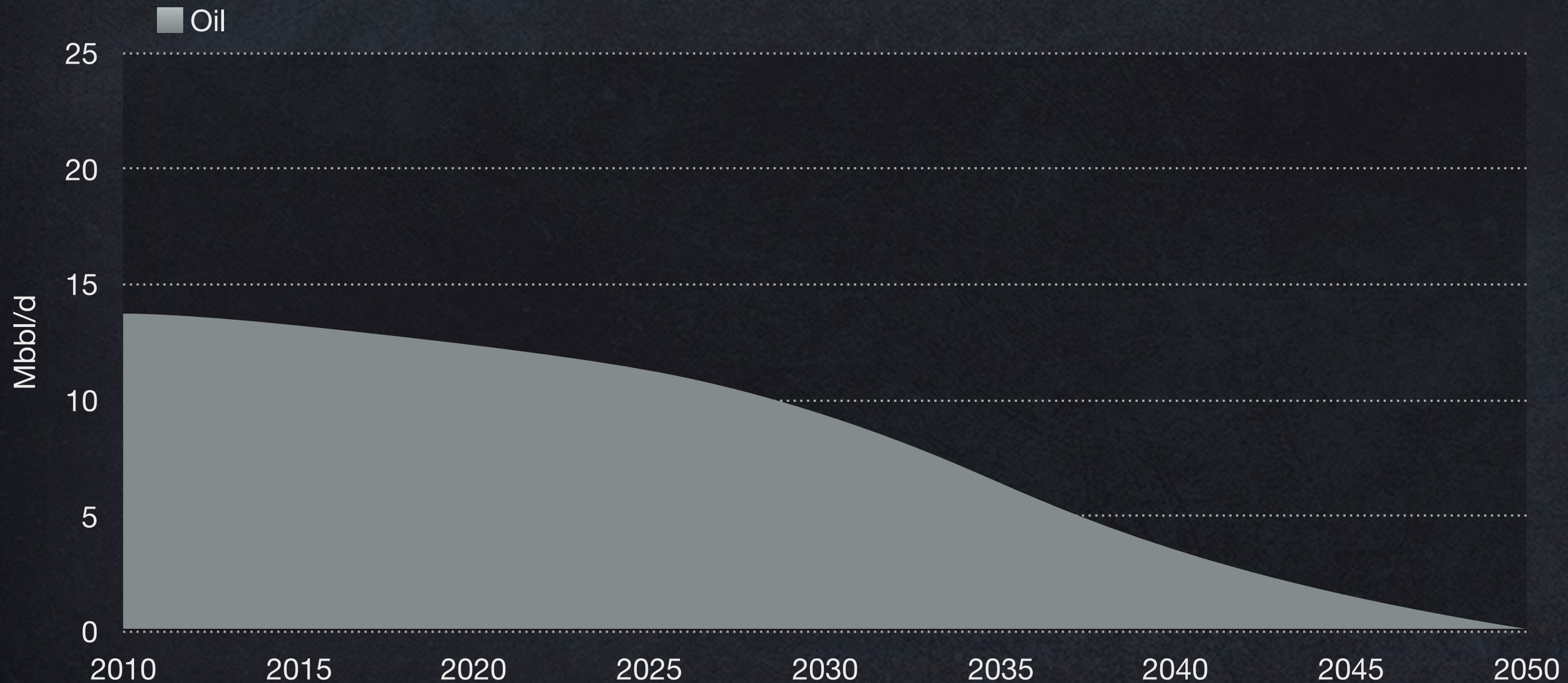
despite 90% more automobility, 118% more trucking, 61% more flying





# Transportation Without Oil

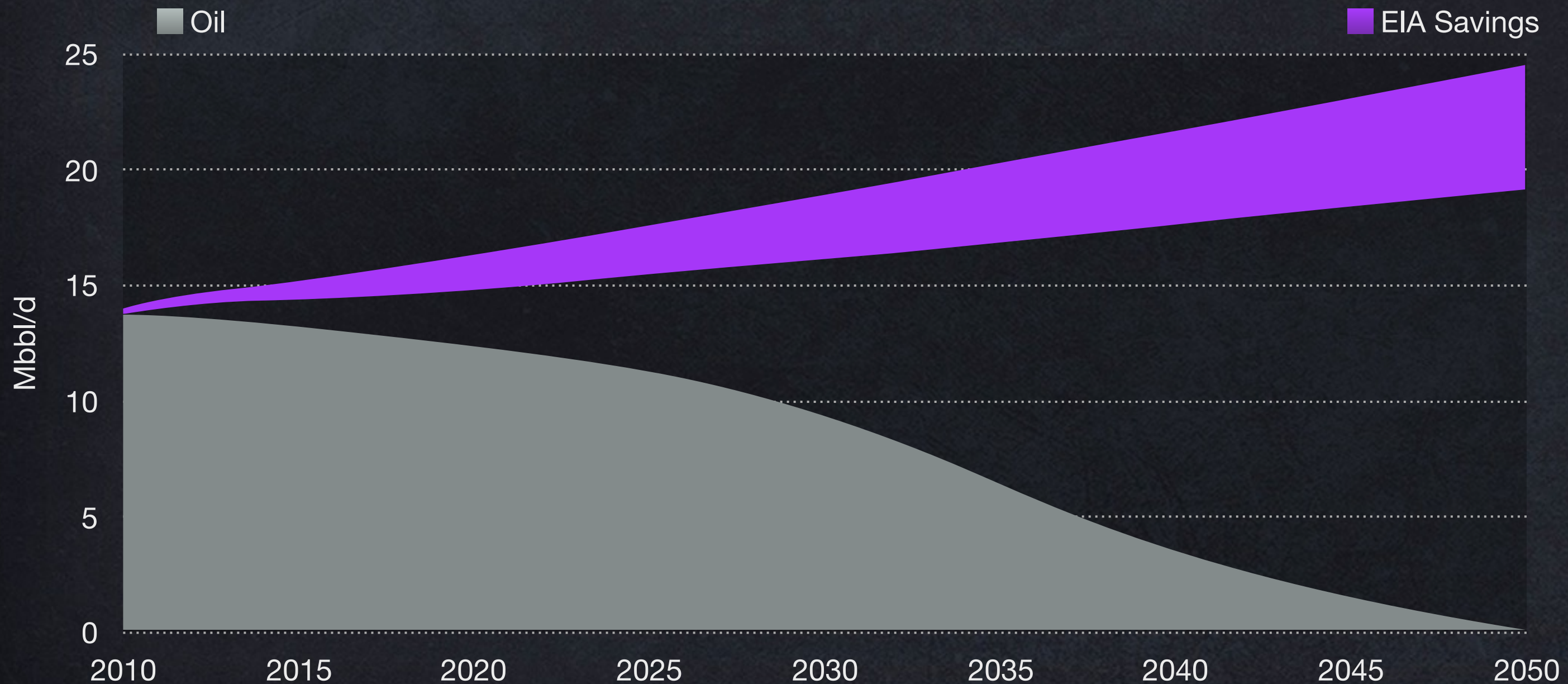
despite 90% more automobility, 118% more trucking, 61% more flying





# Transportation Without Oil

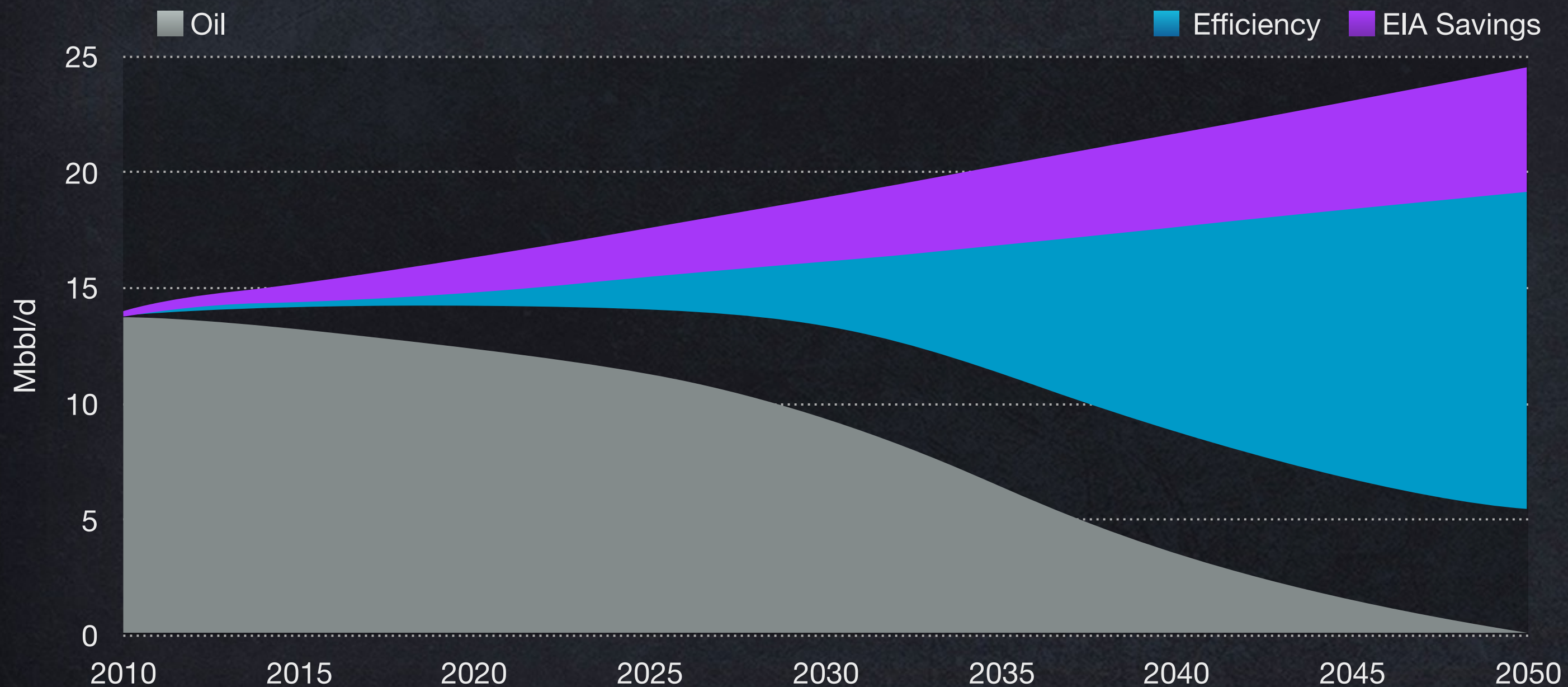
despite 90% more automobility, 118% more trucking, 61% more flying





# Transportation Without Oil

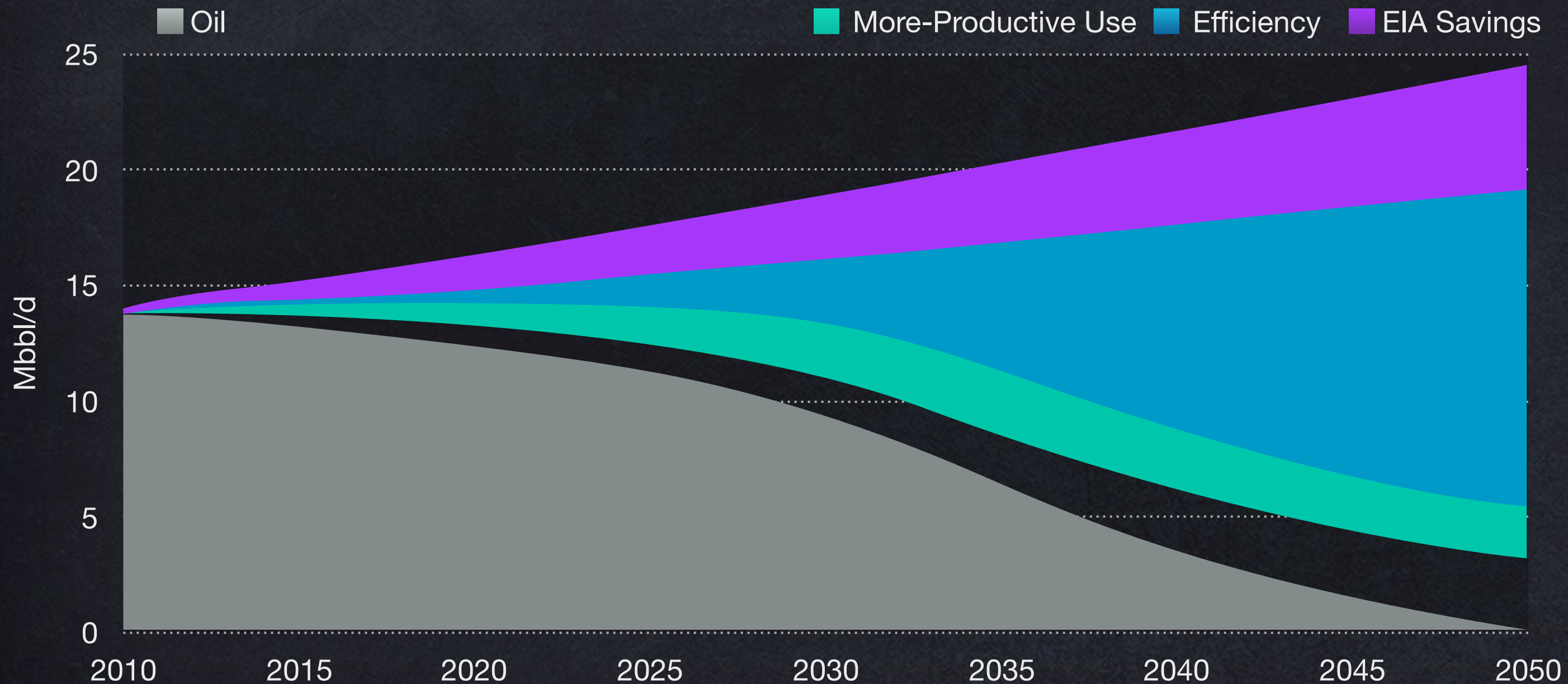
despite 90% more automobility, 118% more trucking, 61% more flying





# Transportation Without Oil

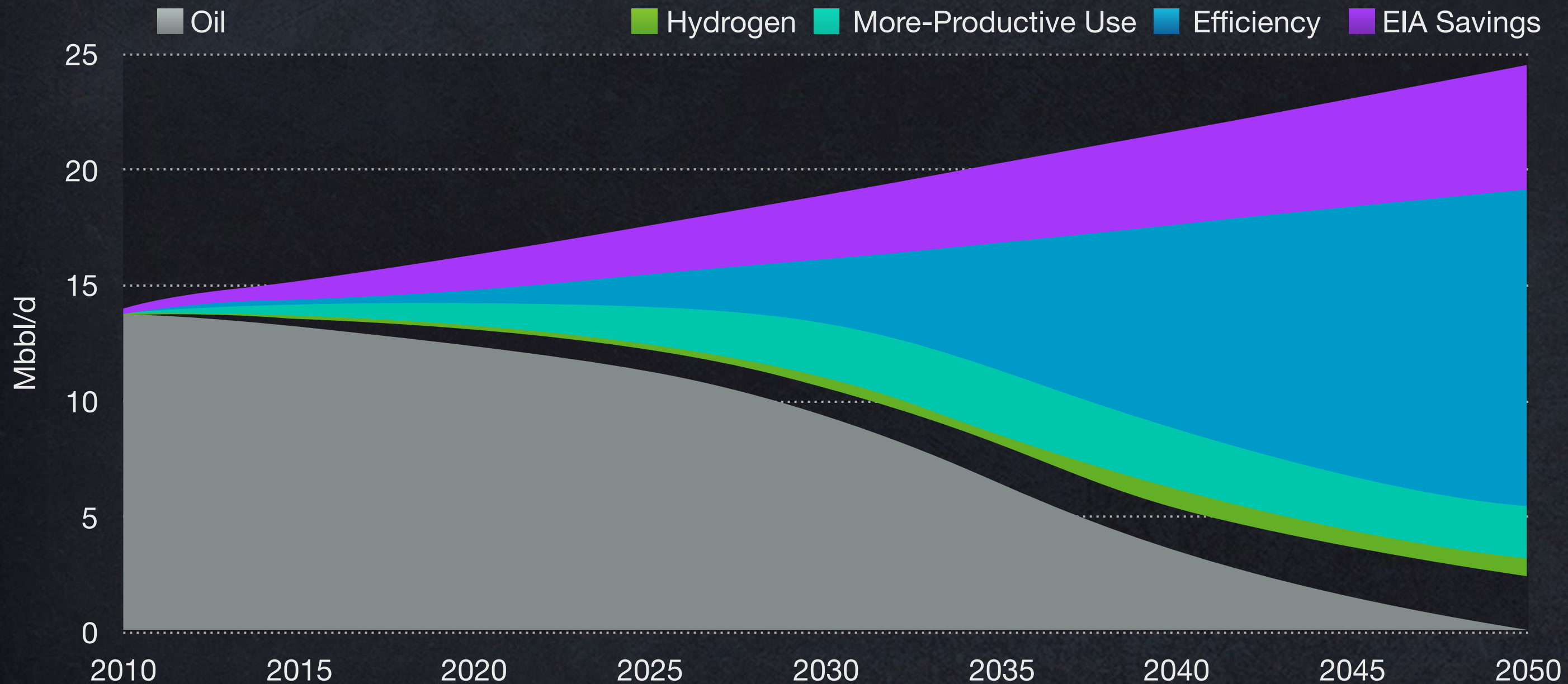
despite 90% more automobility, 118% more trucking, 61% more flying





# Transportation Without Oil

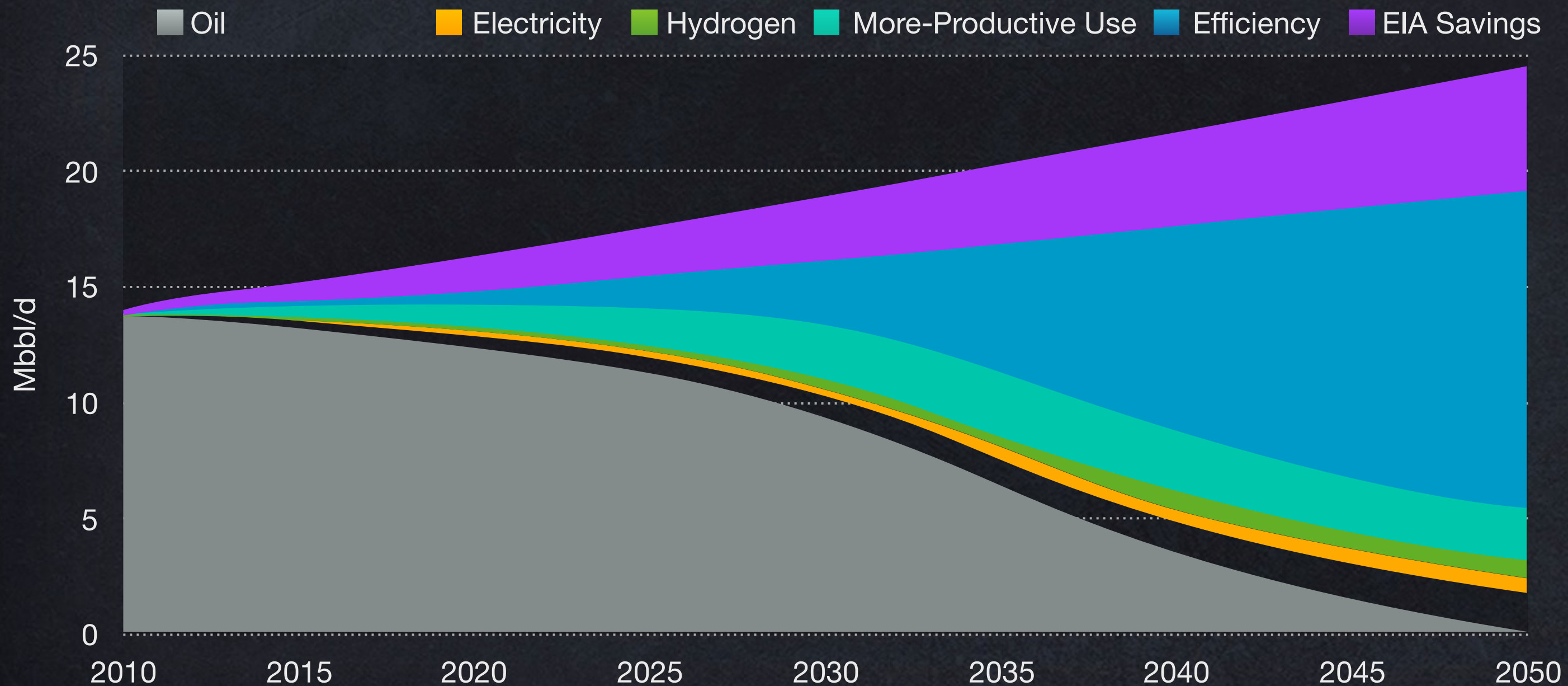
despite 90% more automobility, 118% more trucking, 61% more flying





# Transportation Without Oil

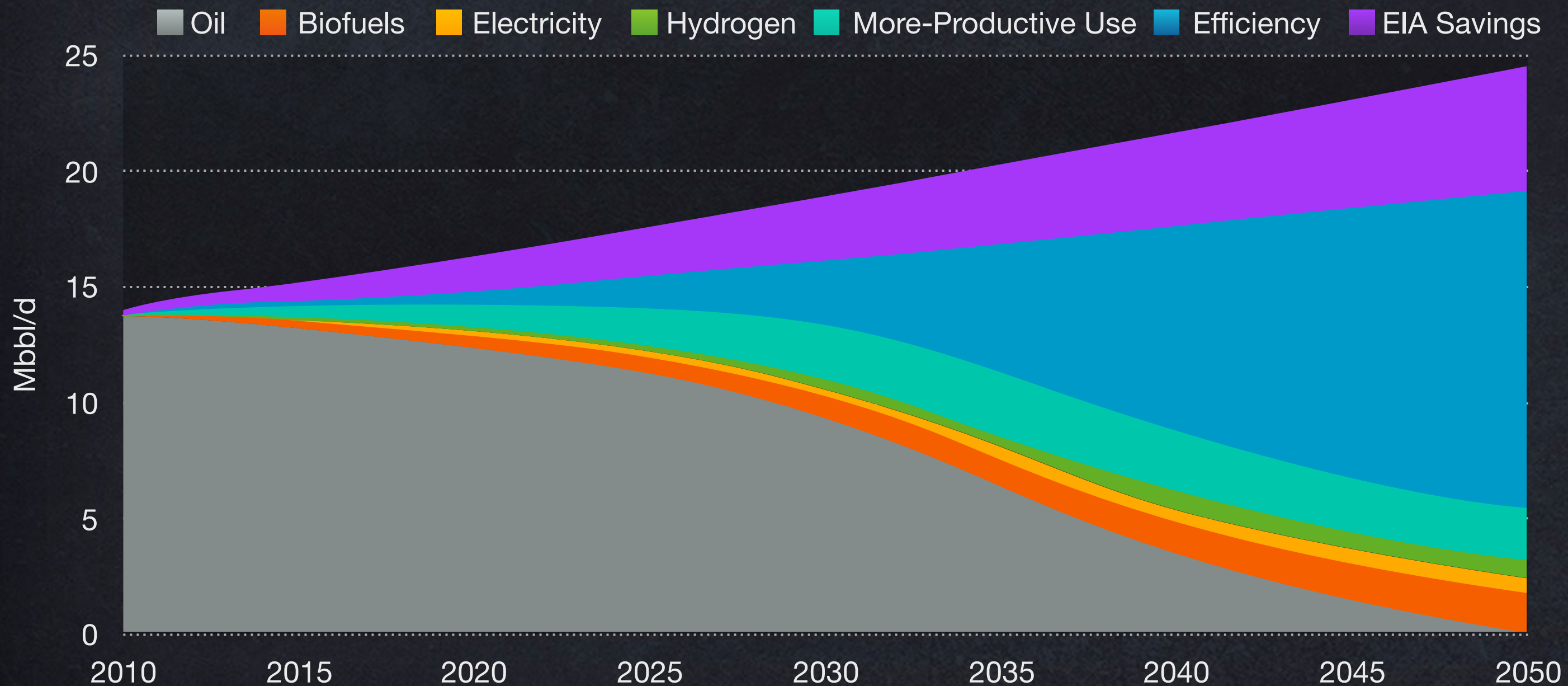
despite 90% more automobility, 118% more trucking, 61% more flying





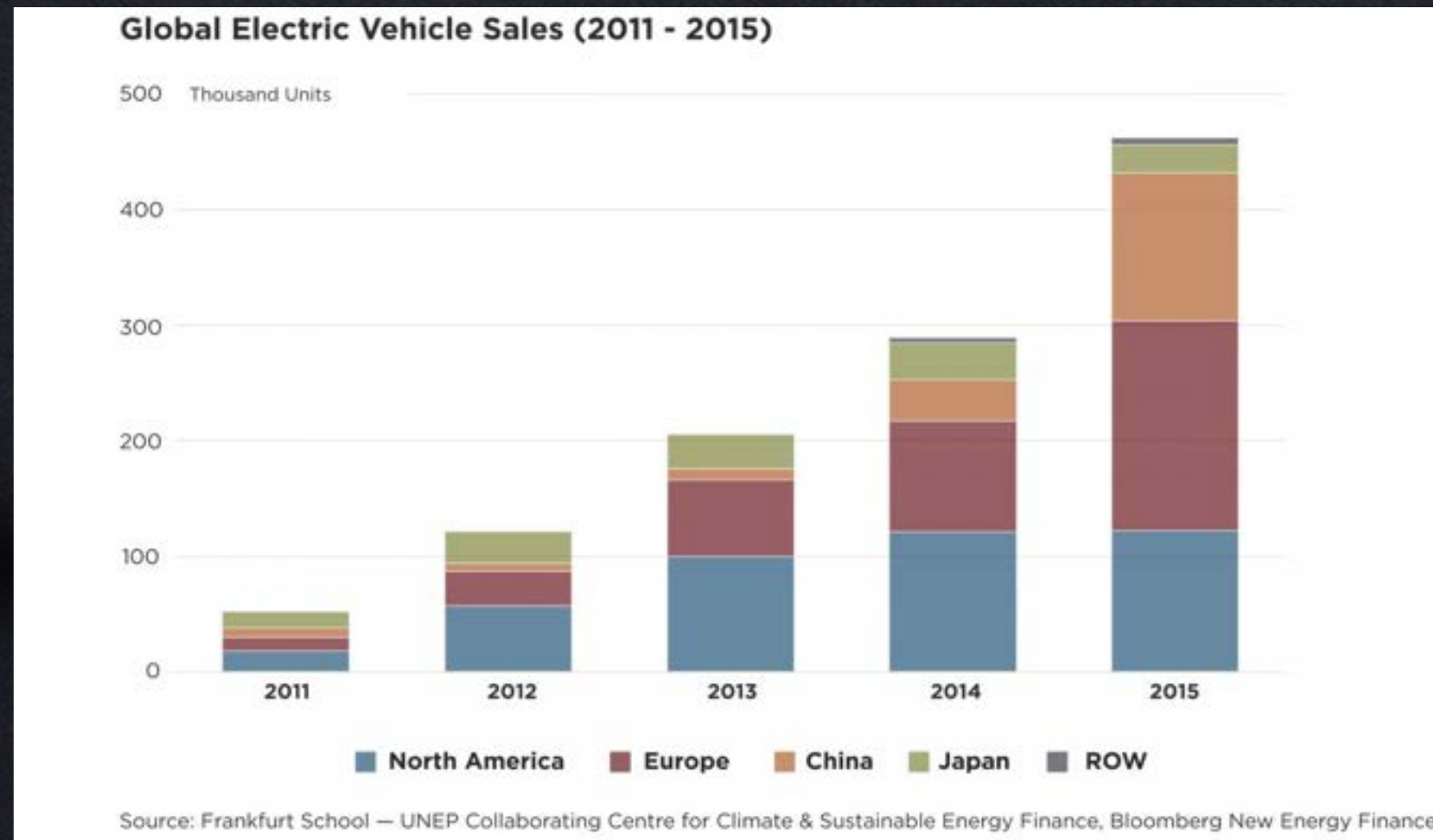
# Transportation Without Oil

despite 90% more automobility, 118% more trucking, 61% more flying





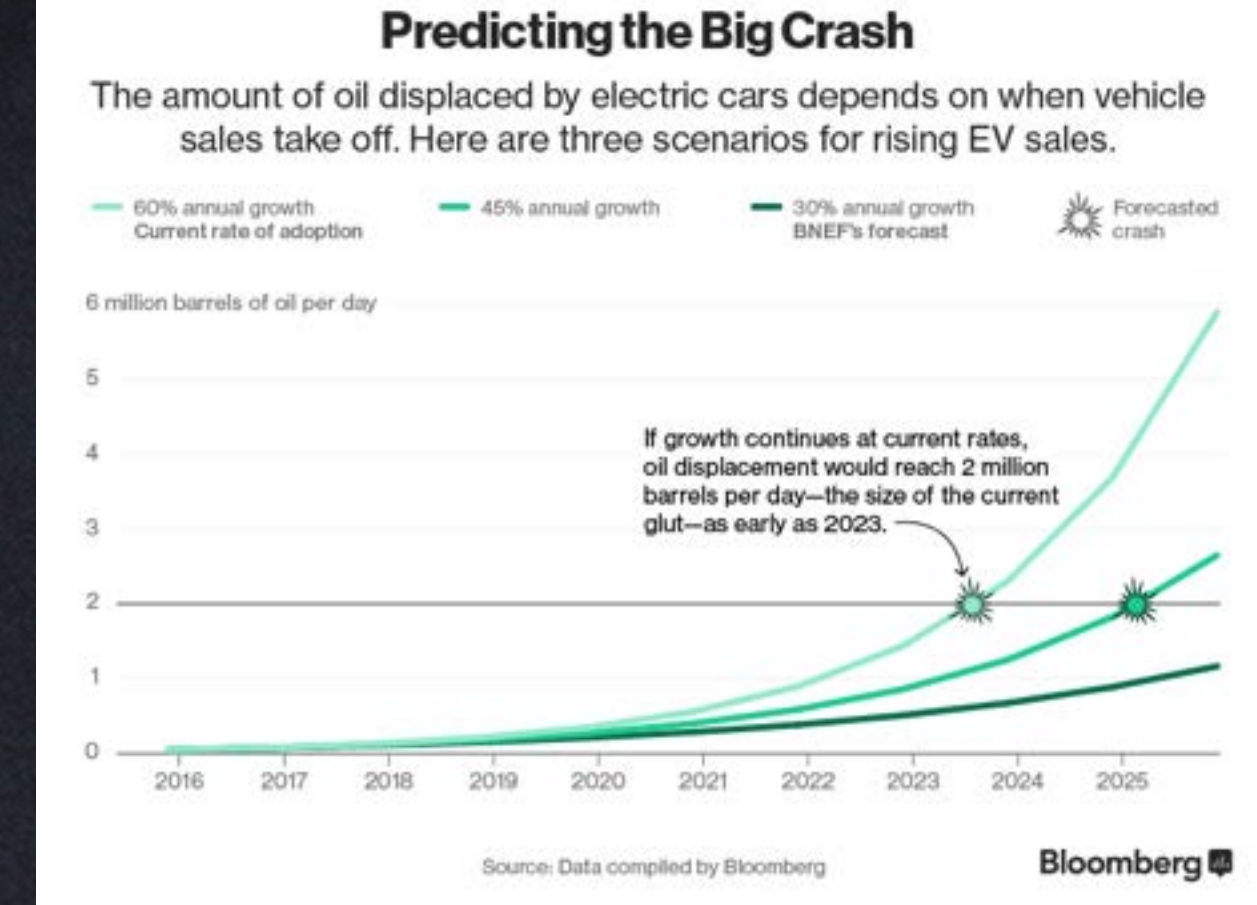
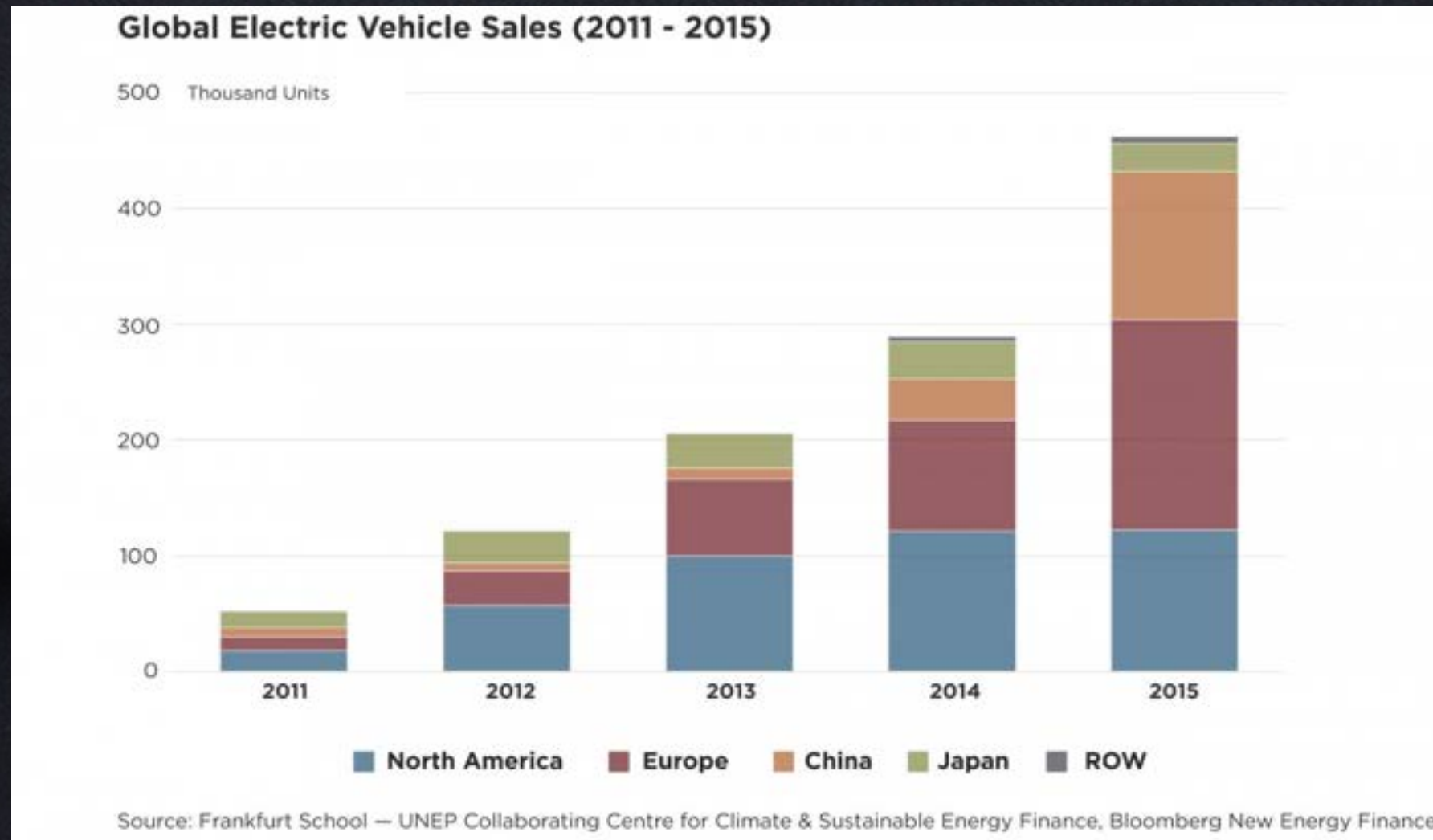
# Rapid Growth of Electrified Cars



U.S. EV sales flattened—but *global* sales are growing ~60%/y



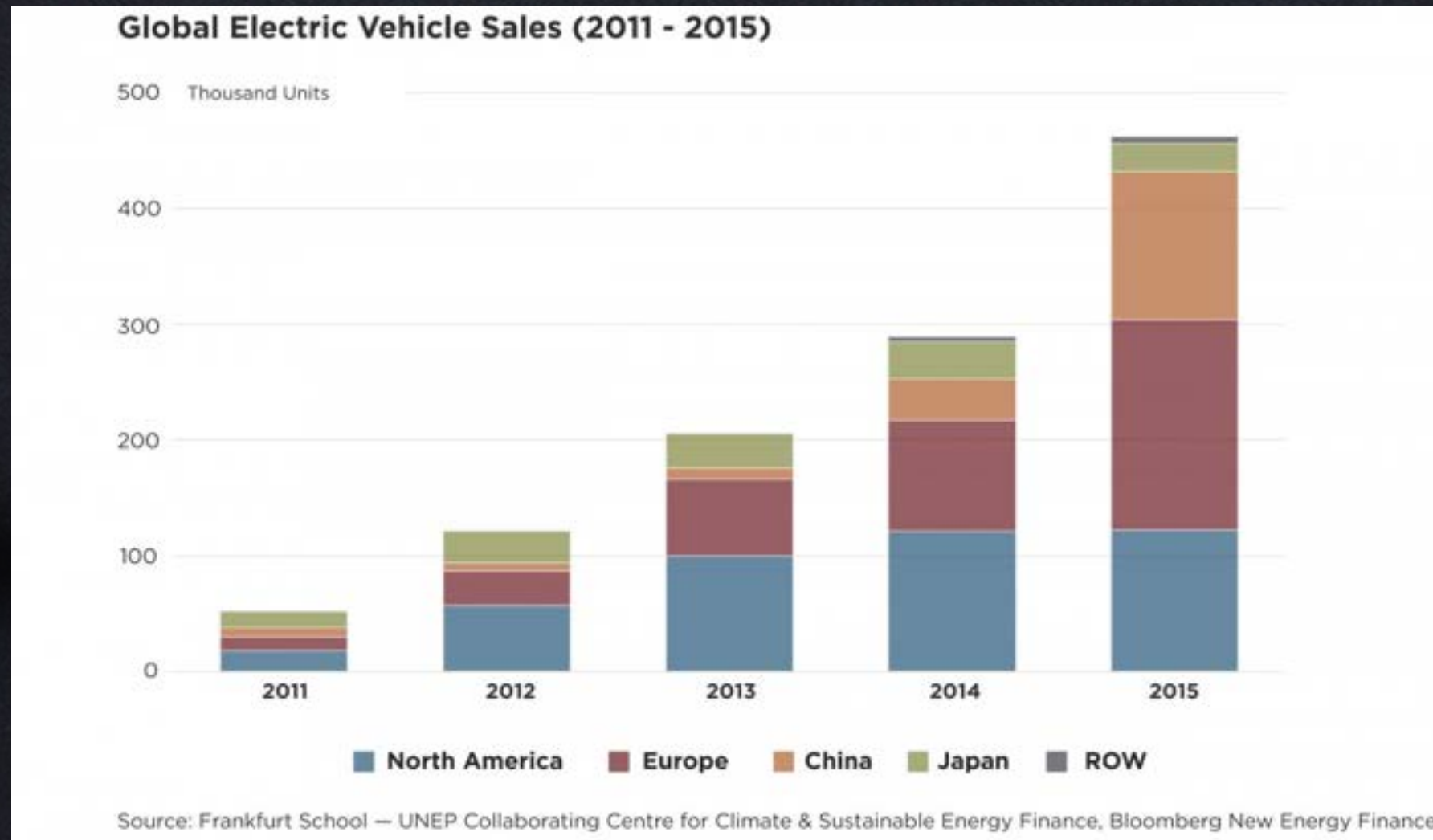
# Rapid Growth of Electrified Cars



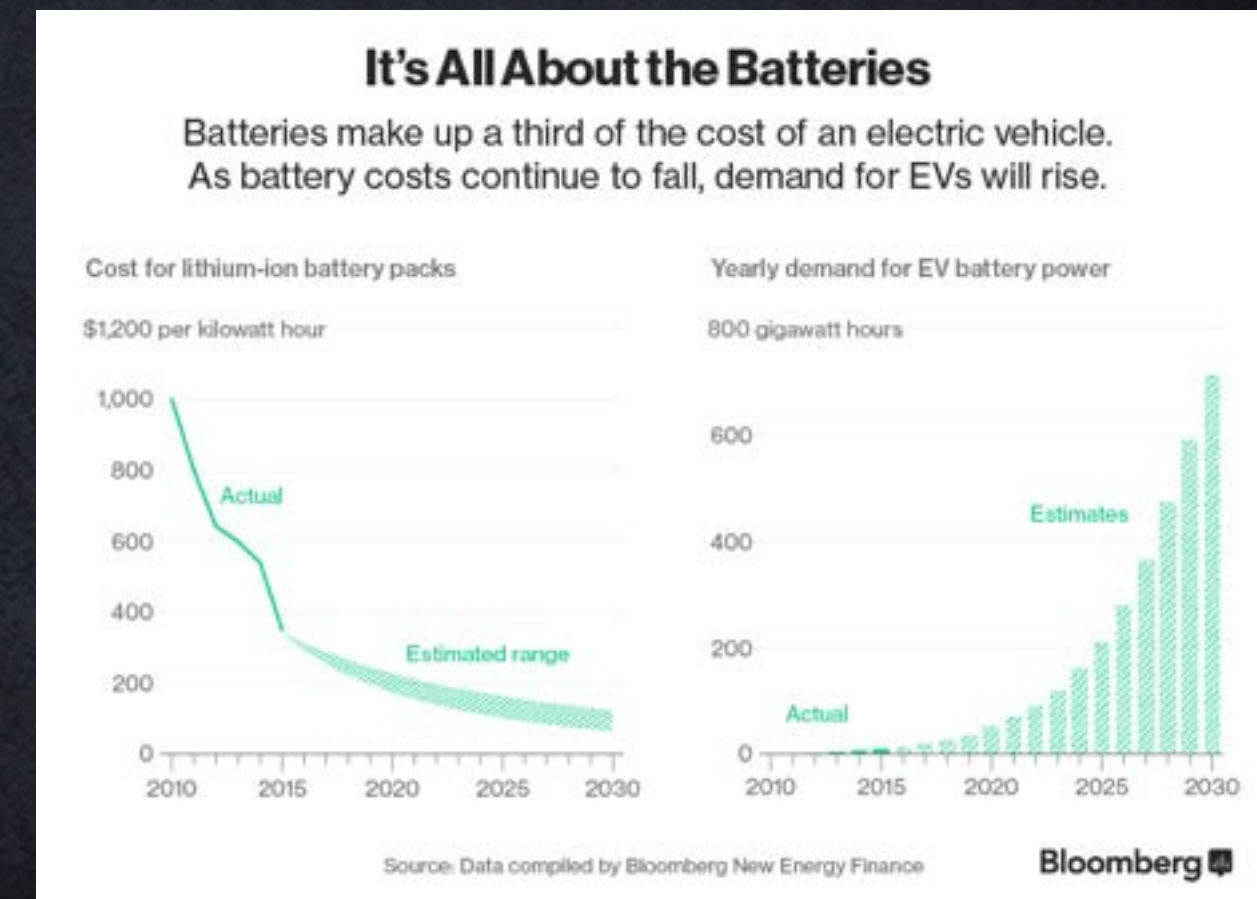
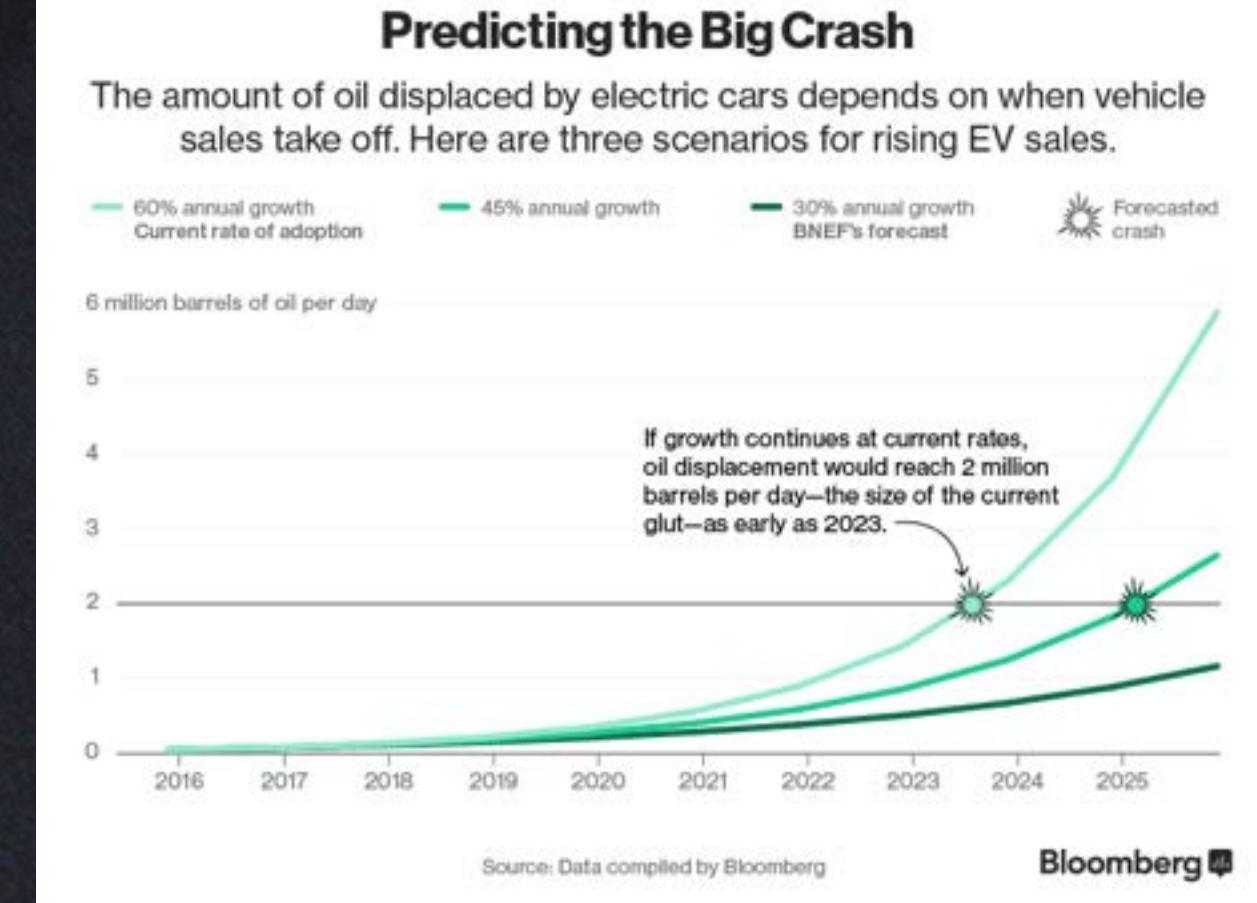
U.S. EV sales flattened—but *global* sales are growing ~60%/y



# Rapid Growth of Electrified Cars



U.S. EV sales flattened—but *global* sales are growing ~60%/y











“We must leave oil  
before it **leaves us.**”

Fatih Birol  
Chief Economist  
International Energy Agency 2008





“We must leave oil  
before it **leaves us.**”

Fatih Birol

~~Chief Economist~~ Executive Director  
International Energy Agency 2008









“I can’t wait  
to see what  
happens  
when our  
industries  
merge.”



Intensity decrease has had 31× the impact of renewable growth

U.S. primary energy use (quadrillion BTU/y)

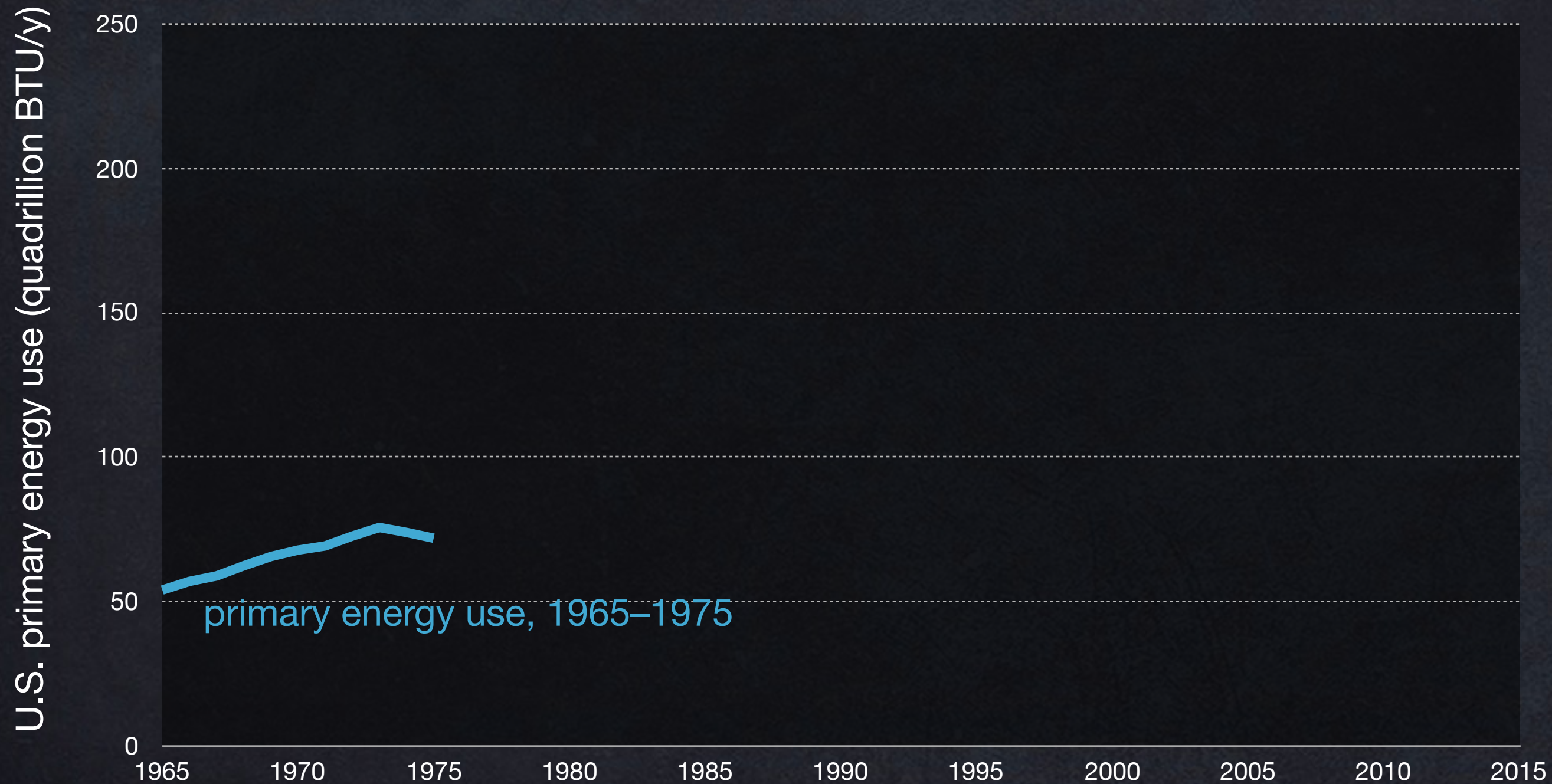


# Intensity decrease has had 31× the impact of renewable growth



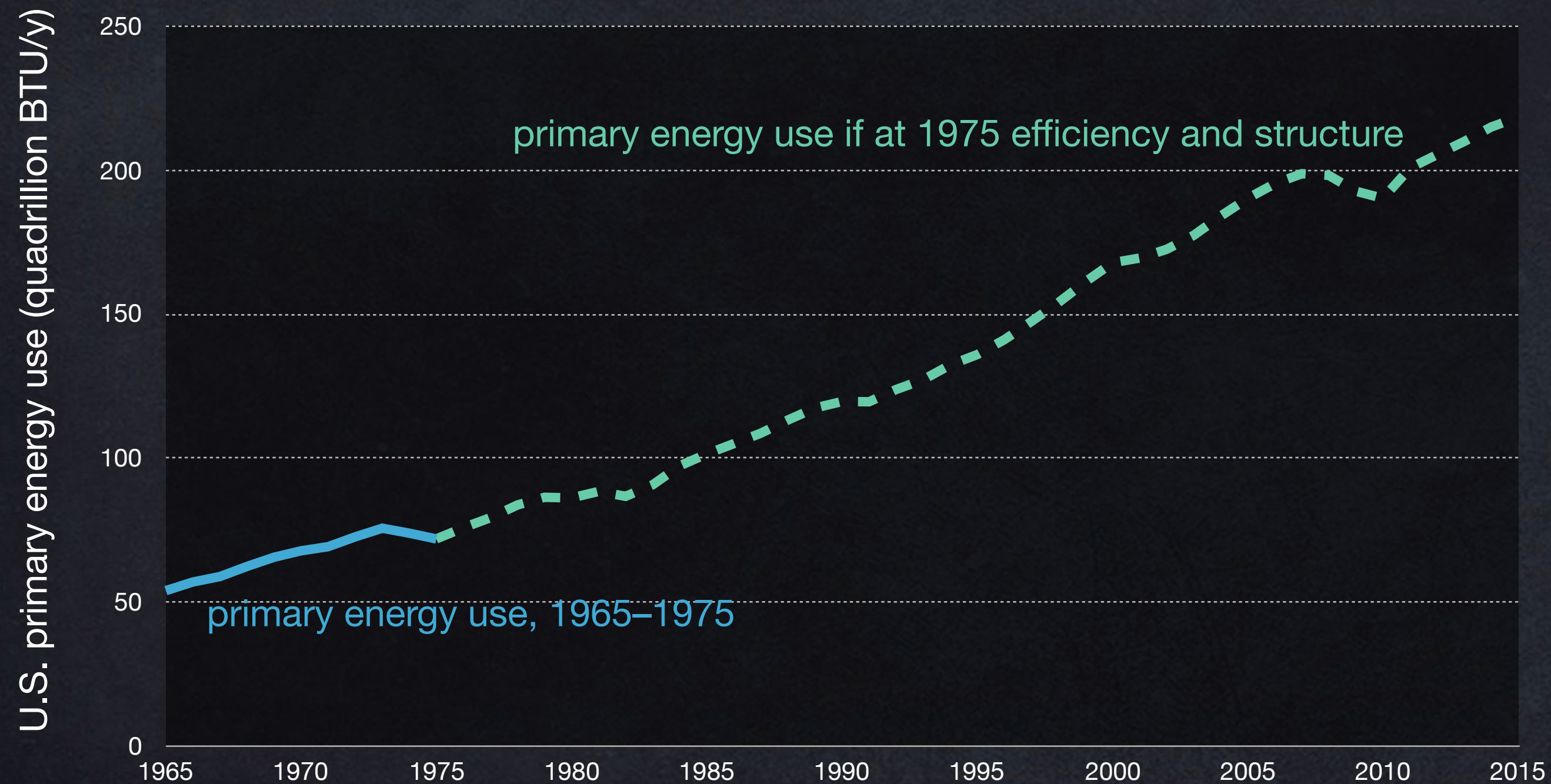


# Intensity decrease has had 31× the impact of renewable growth



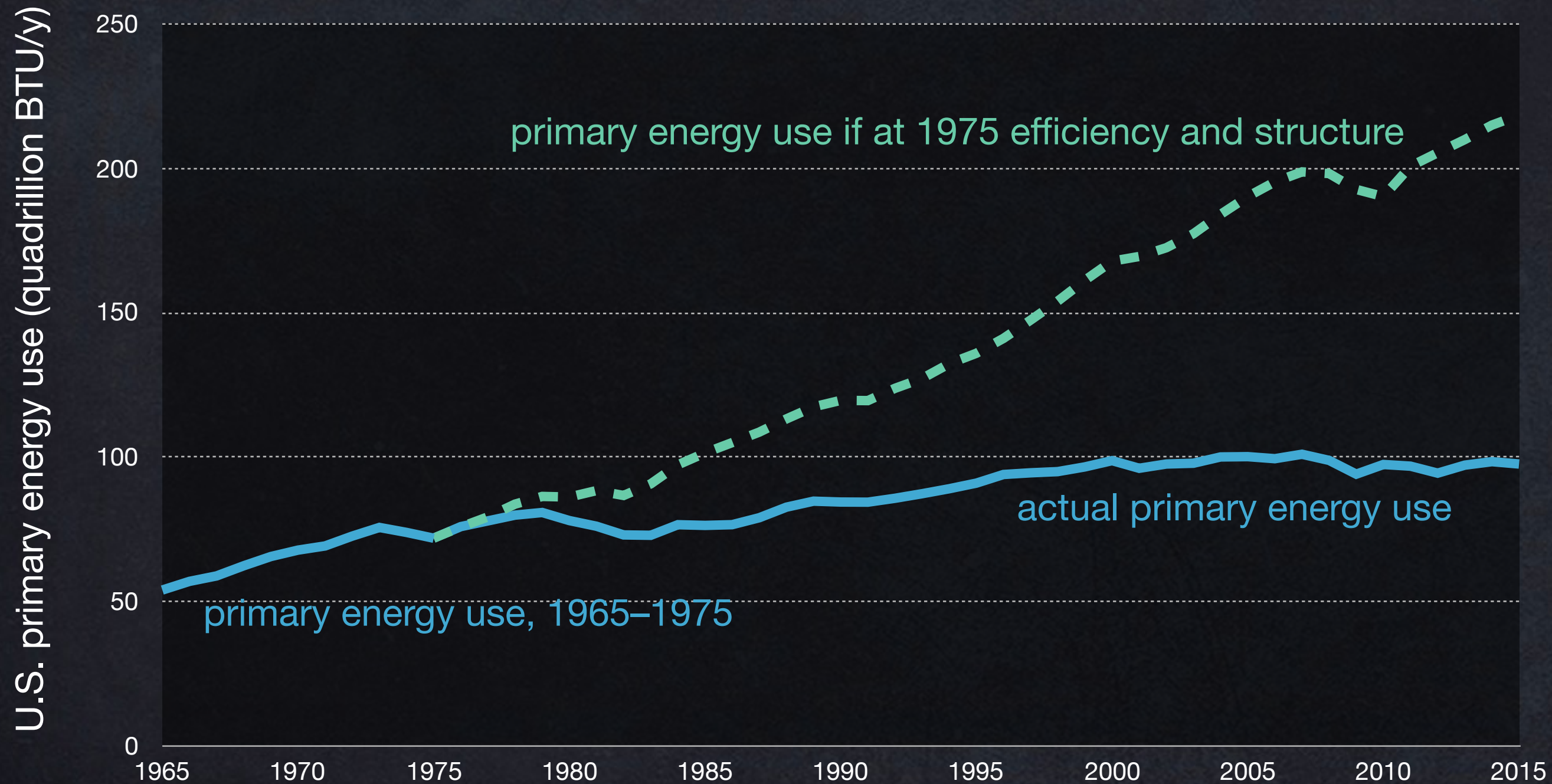


# Intensity decrease has had 31× the impact of renewable growth



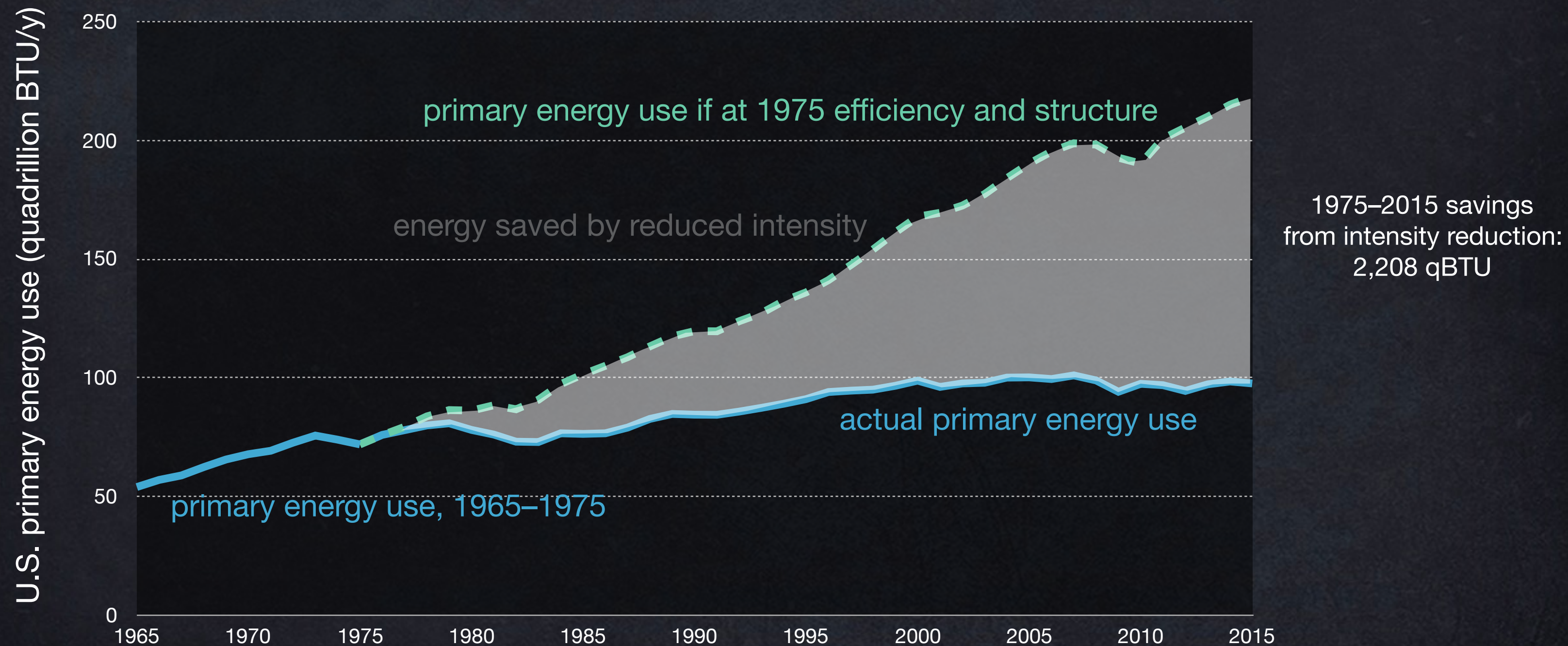


# Intensity decrease has had 31× the impact of renewable growth



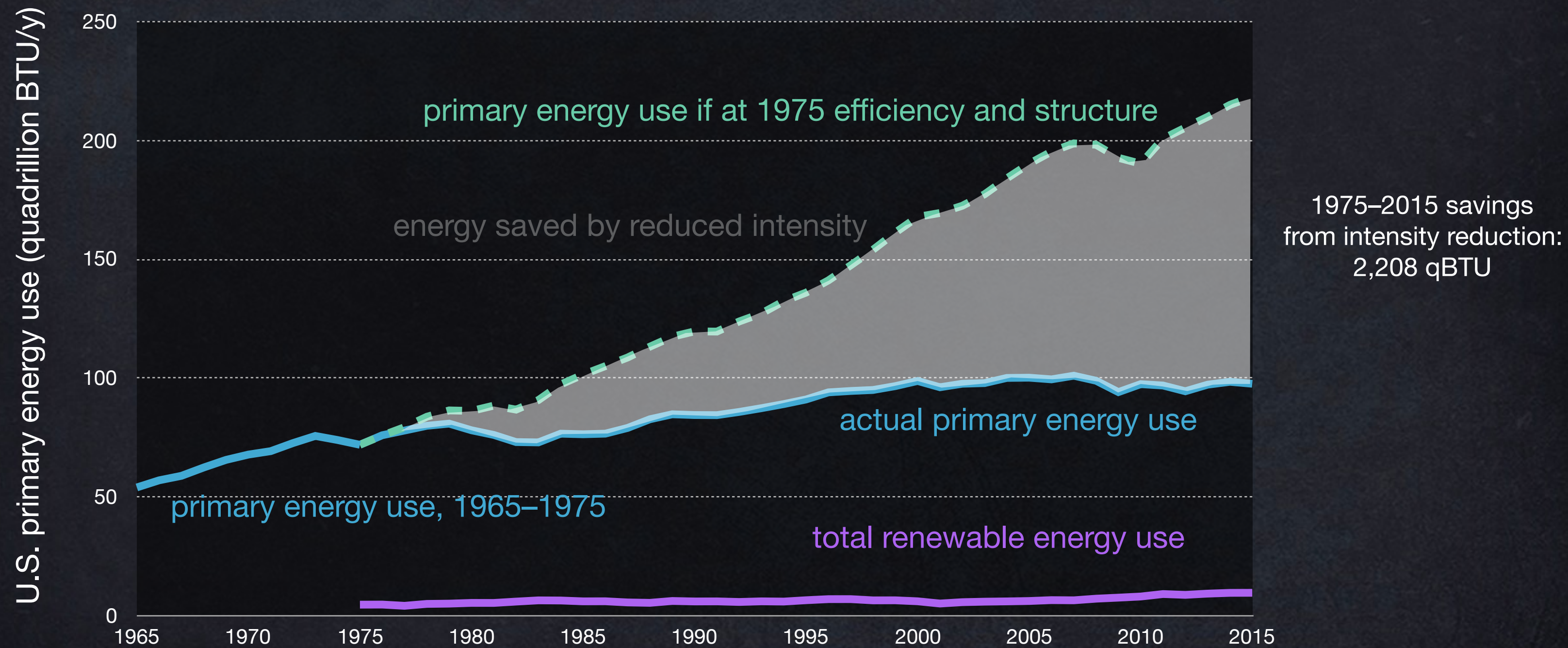


# Intensity decrease has had 31× the impact of renewable growth



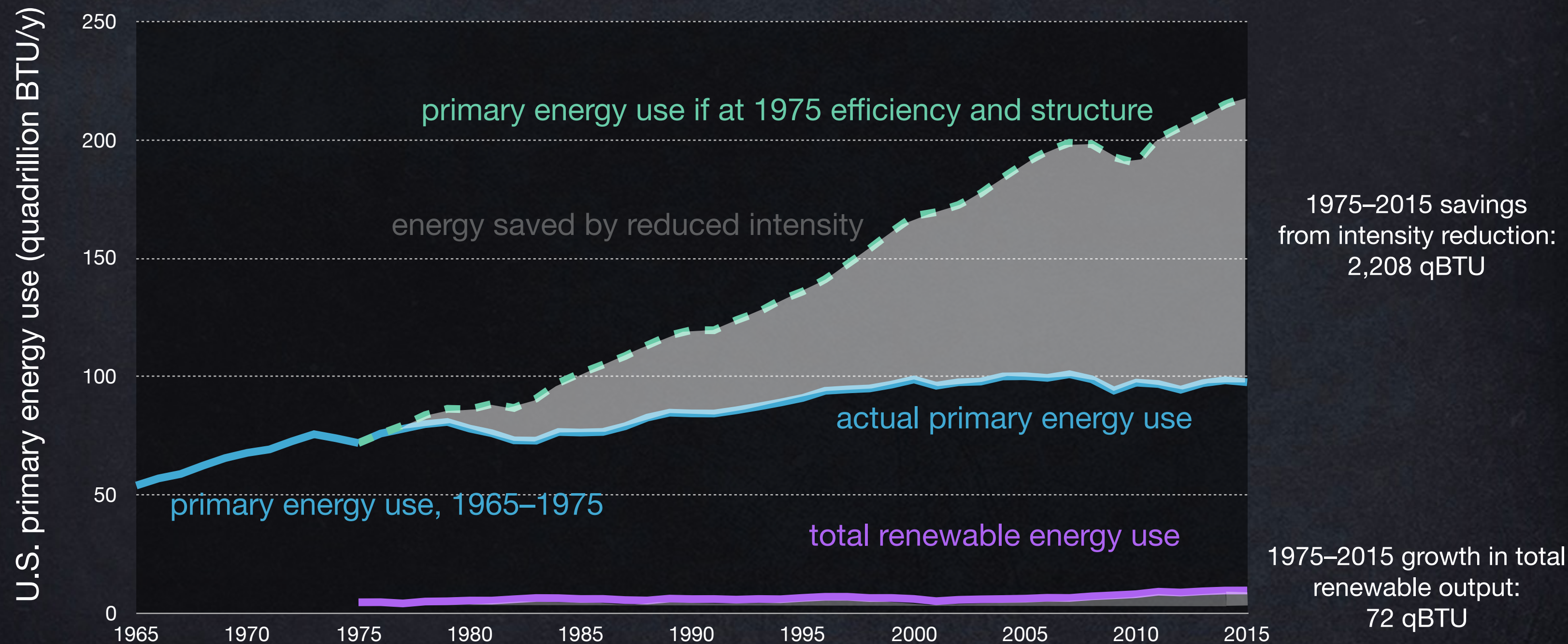


# Intensity decrease has had 31× the impact of renewable growth





# Intensity decrease has had 31× the impact of renewable growth



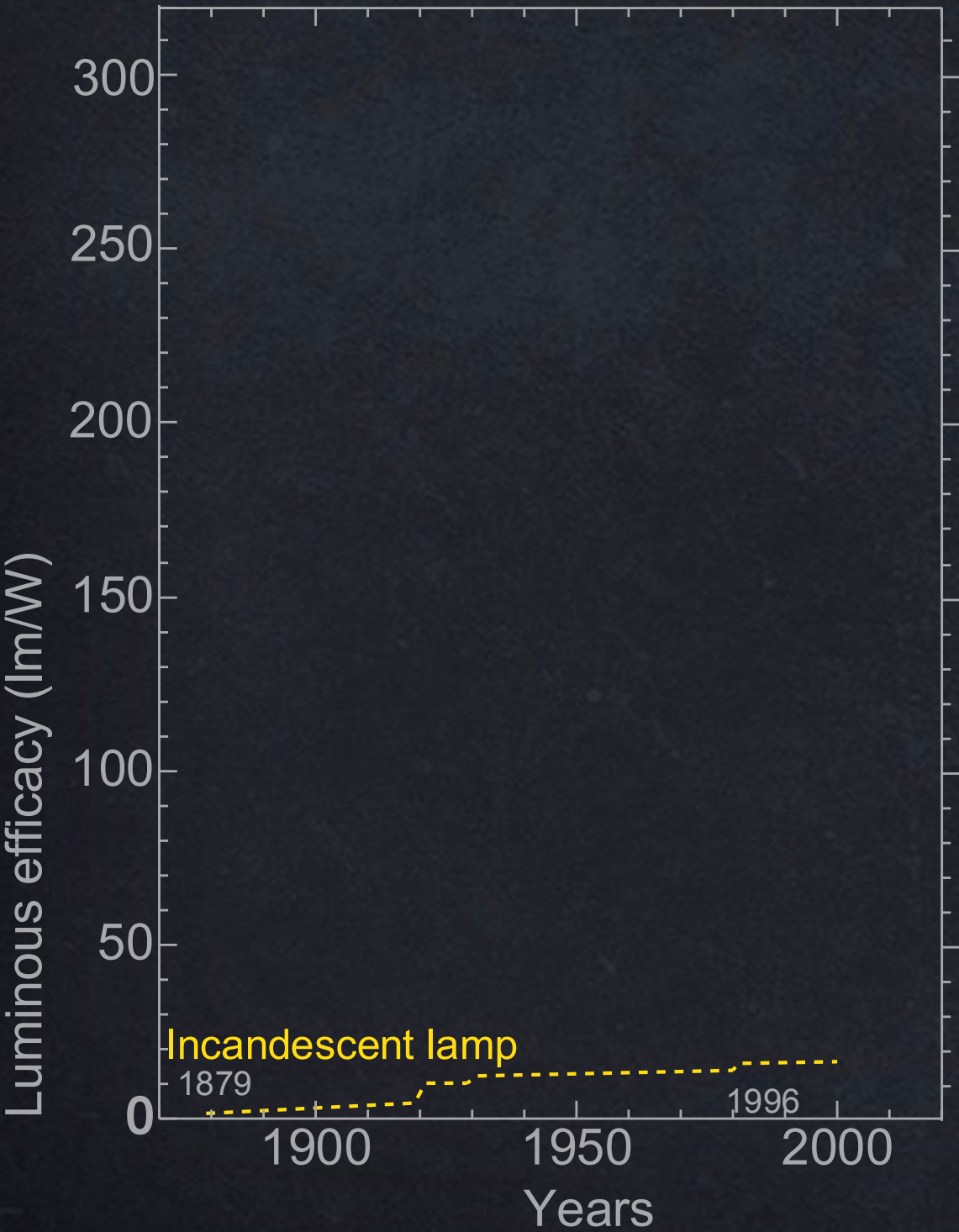


# LED and PV

Sources: L: courtesy of Dr. Yukio Narukawa (Nichia Corp., Tokushima, Japan) from *J. Physics. D: Appl. Phys.* **43**(2010) 354002, doi:10.1088/0022-3727/43/35/354002, updated by RMI with CREE lm/W data, 2015, [www.cree.com/News-and-Events/Cree-News/Press-Releases/2014/March/300LPW-LED-barrier](http://www.cree.com/News-and-Events/Cree-News/Press-Releases/2014/March/300LPW-LED-barrier); R: RMI analysis, at average 2013 USEIA fossil-fueled generation efficiencies and each year's real fuel costs (no O&M); utility-scale PV: LBNL, *Utility-Scale Solar 2013* (Sep 2014), Fig. 18; onshore wind: USDOE, *2013 Wind Technologies Market Report* (Aug 2014), "Windbelt" (Interior zone) windfarms' average PPA; German feed-in tariff (falls with cost to yield ~6%/y real return): Fraunhofer ISE, *Cost Perspective, Grid and Market Integration of Renewable Energies*, p 6 (Jan 2014); all sources net of subsidies; graph inspired by 2014 "Terror dome" slide, Michael Parker, Bernstein Alliance



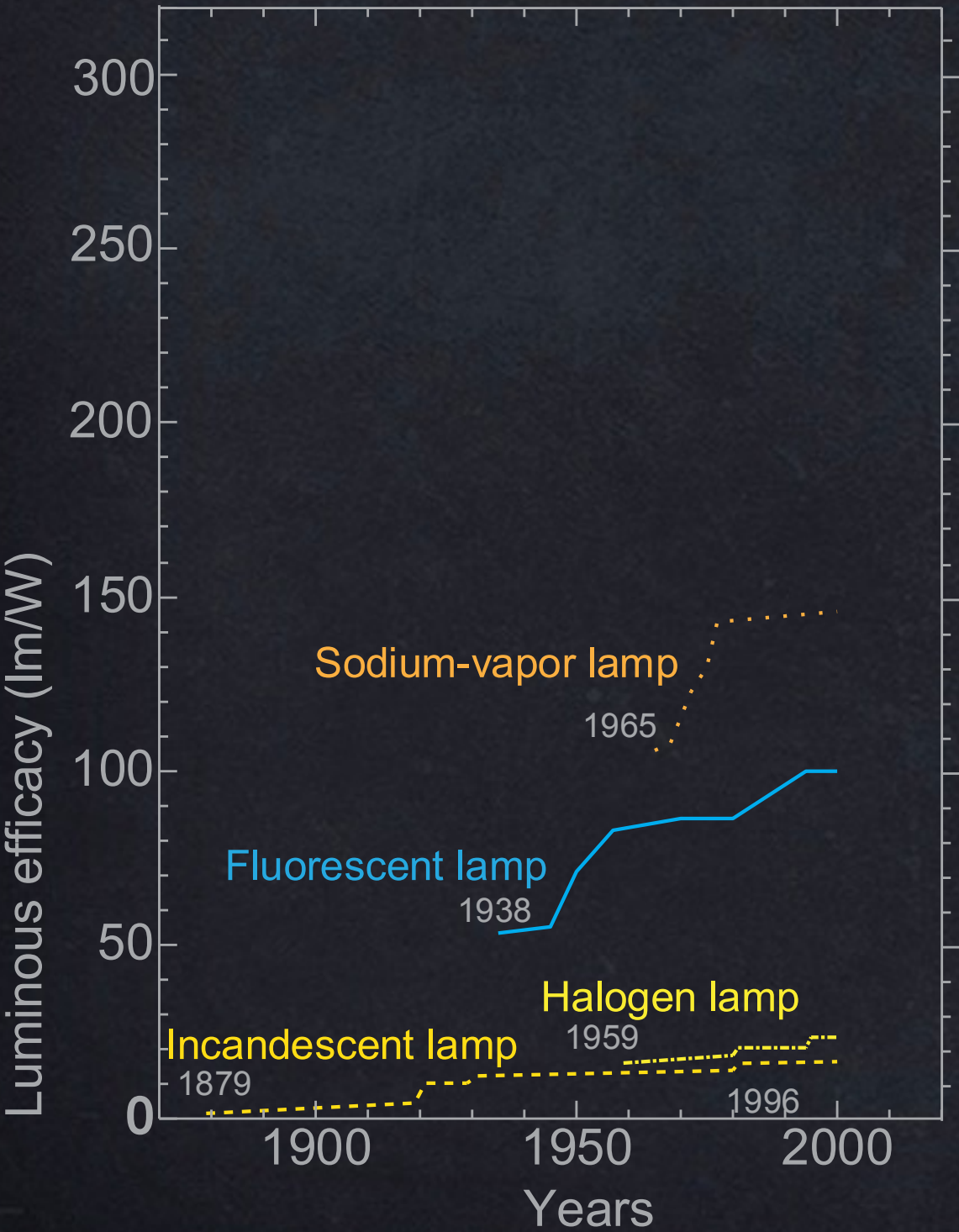
# LED and PV



Sources: L: courtesy of Dr. Yukio Narukawa (Nichia Corp., Tokushima, Japan) from *J. Physics. D: Appl. Phys.* **43**(2010) 354002, doi:10.1088/0022-3727/43/35/354002, updated by RMI with CREE lm/W data, 2015, [www.cree.com/News-and-Events/Cree-News/Press-Releases/2014/March/300LPW-LED-barrier](http://www.cree.com/News-and-Events/Cree-News/Press-Releases/2014/March/300LPW-LED-barrier); R: RMI analysis, at average 2013 USEIA fossil-fueled generation efficiencies and each year's real fuel costs (no O&M); utility-scale PV: LBNL, *Utility-Scale Solar 2013* (Sep 2014), Fig. 18; onshore wind: USDOE, *2013 Wind Technologies Market Report* (Aug 2014), "Windbelt" (Interior zone) windfarms' average PPA; German feed-in tariff (falls with cost to yield ~6%/y real return): Fraunhofer ISE, *Cost Perspective, Grid and Market Integration of Renewable Energies*, p 6 (Jan 2014); all sources net of subsidies; graph inspired by 2014 "Terror dome" slide, Michael Parker, Bernstein Alliance



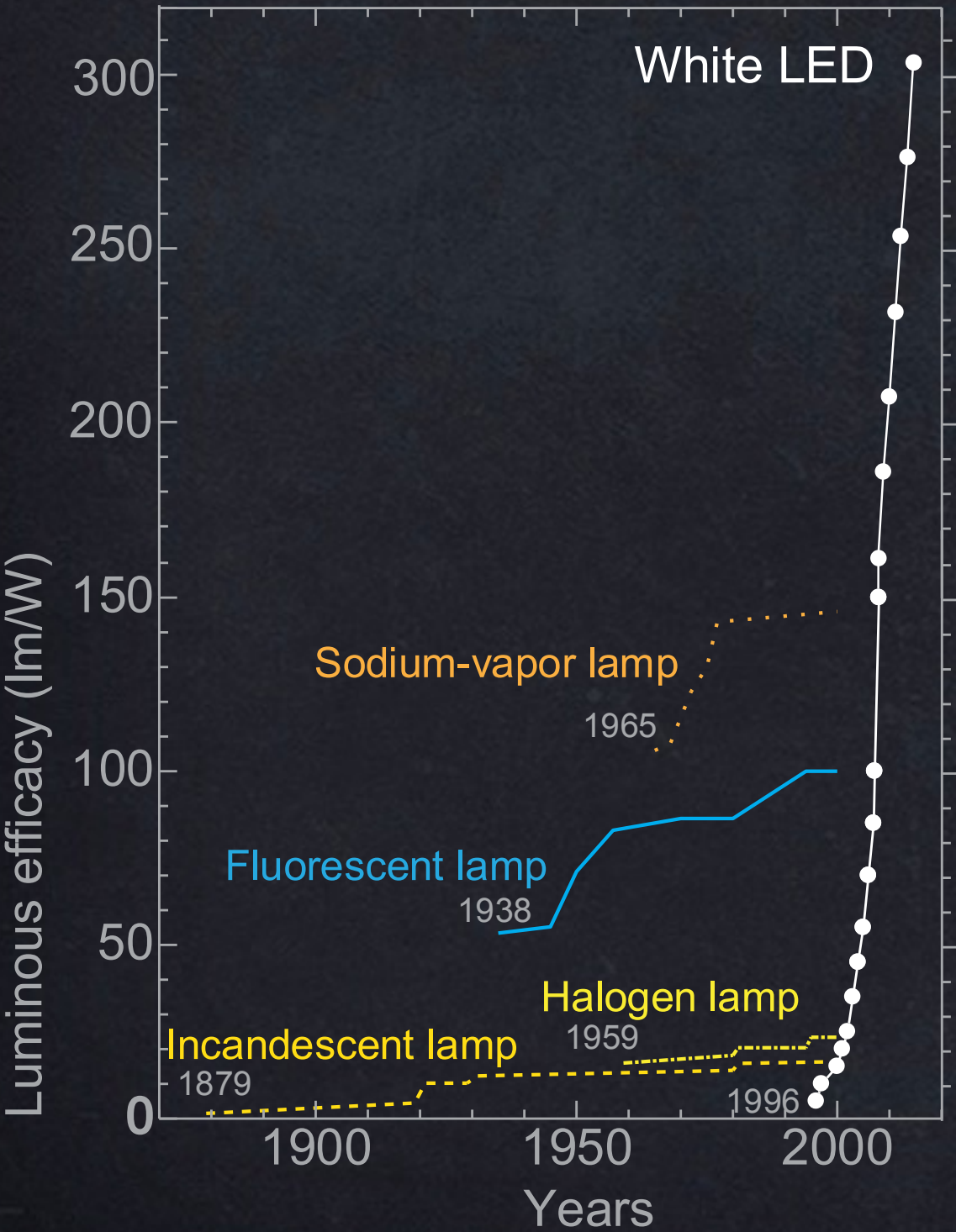
# LED and PV



Sources: L: courtesy of Dr. Yukio Narukawa (Nichia Corp., Tokushima, Japan) from *J. Physics. D: Appl. Phys.* **43**(2010) 354002, doi:10.1088/0022-3727/43/35/354002, updated by RMI with CREE lm/W data, 2015, [www.cree.com/News-and-Events/Cree-News/Press-Releases/2014/March/300LPW-LED-barrier](http://www.cree.com/News-and-Events/Cree-News/Press-Releases/2014/March/300LPW-LED-barrier); R: RMI analysis, at average 2013 USEIA fossil-fueled generation efficiencies and each year's real fuel costs (no O&M); utility-scale PV: LBNL, *Utility-Scale Solar 2013* (Sep 2014), Fig. 18; onshore wind: USDOE, *2013 Wind Technologies Market Report* (Aug 2014), "Windbelt" (Interior zone) windfarms' average PPA; German feed-in tariff (falls with cost to yield ~6%/y real return): Fraunhofer ISE, *Cost Perspective, Grid and Market Integration of Renewable Energies*, p 6 (Jan 2014); all sources net of subsidies; graph inspired by 2014 "Terror dome" slide, Michael Parker, Bernstein Alliance



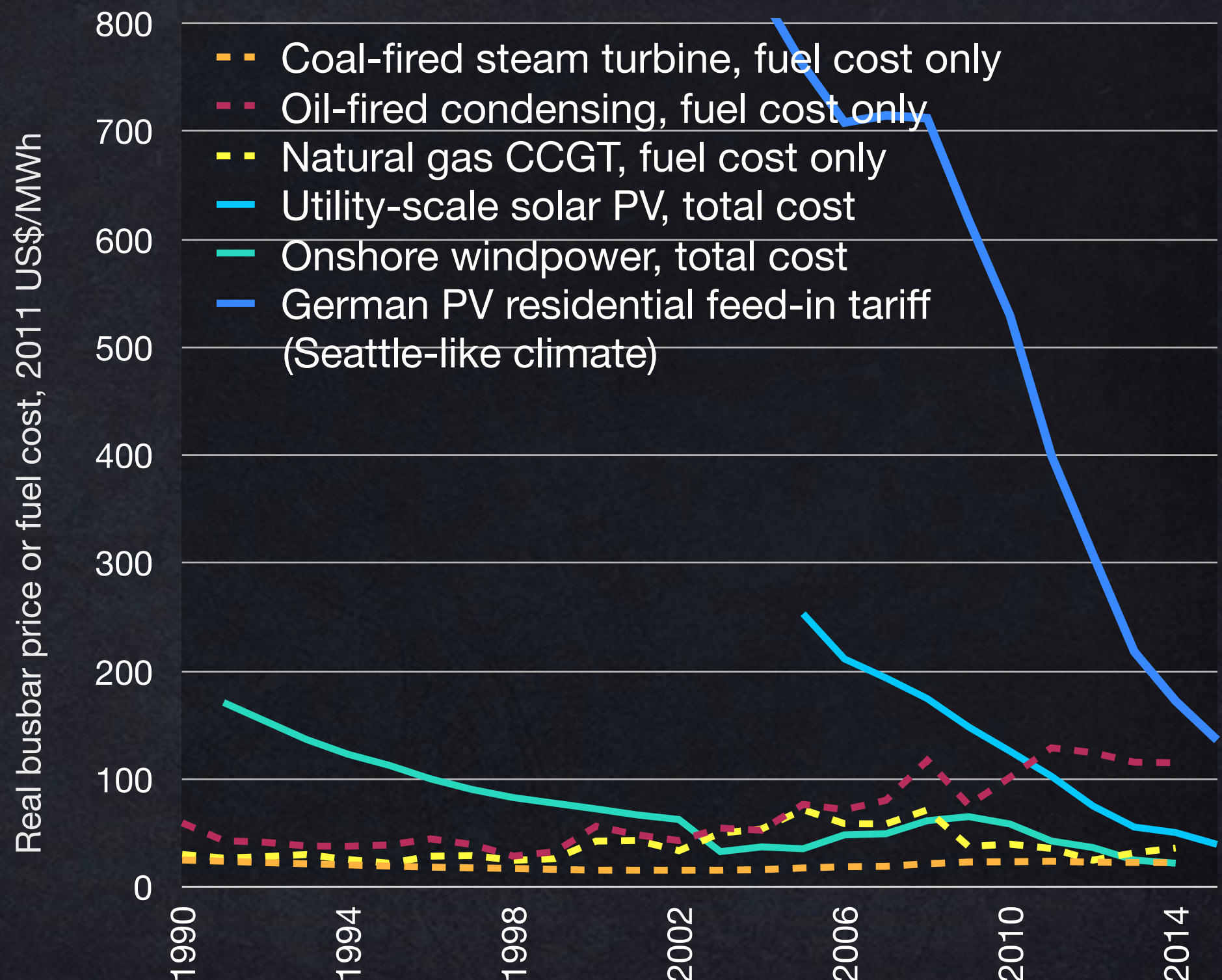
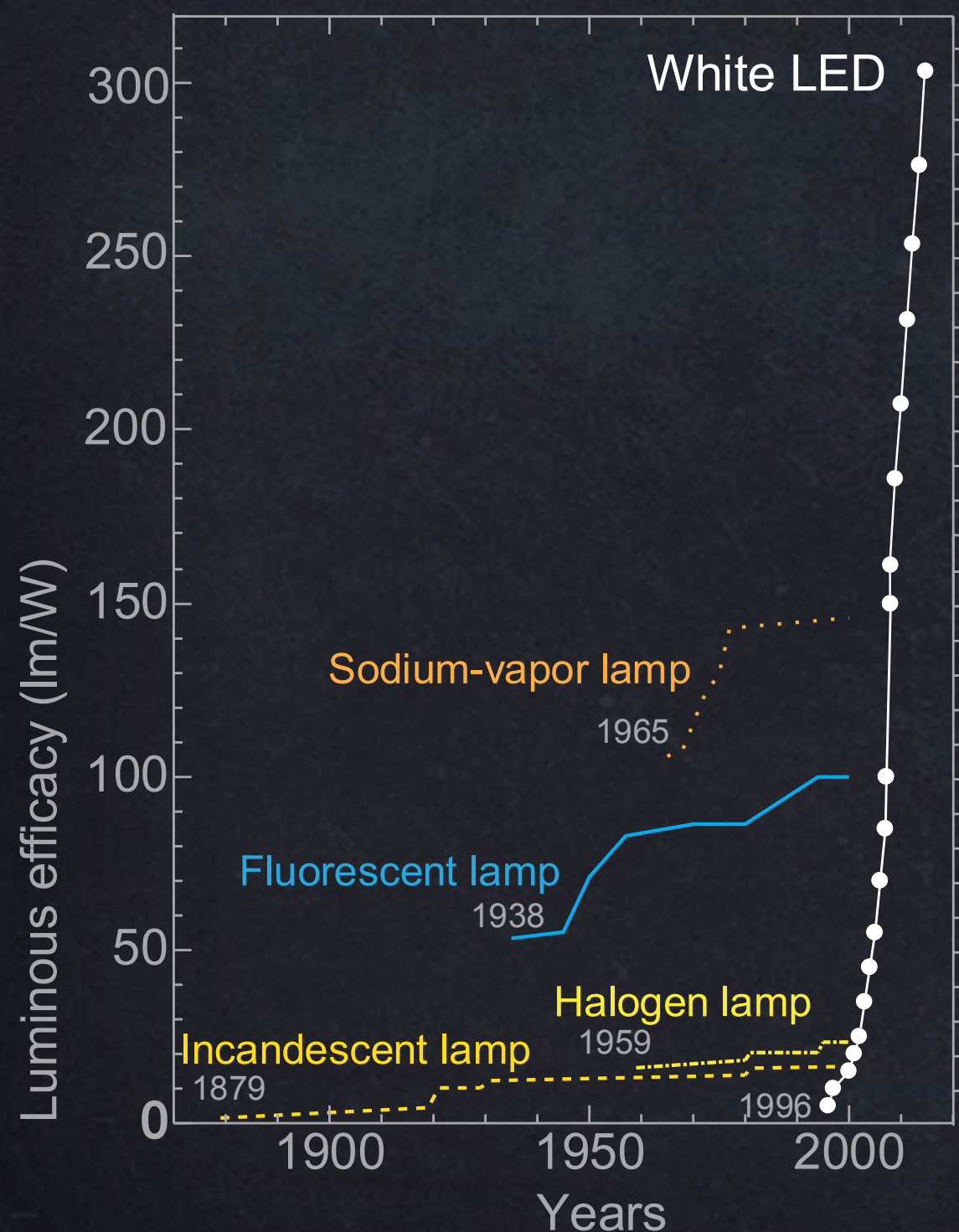
# LED and PV



Sources: L: courtesy of Dr. Yukio Narukawa (Nichia Corp., Tokushima, Japan) from *J. Physics. D: Appl. Phys.* **43**(2010) 354002, doi:10.1088/0022-3727/43/35/354002, updated by RMI with CREE lm/W data, 2015, [www.cree.com/News-and-Events/Cree-News/Press-Releases/2014/March/300LPW-LED-barrier](http://www.cree.com/News-and-Events/Cree-News/Press-Releases/2014/March/300LPW-LED-barrier); R: RMI analysis, at average 2013 USEIA fossil-fueled generation efficiencies and each year's real fuel costs (no O&M); utility-scale PV: LBNL, *Utility-Scale Solar 2013* (Sep 2014), Fig. 18; onshore wind: USDOE, 2013 *Wind Technologies Market Report* (Aug 2014), "Windbelt" (Interior zone) windfarms' average PPA; German feed-in tariff (falls with cost to yield ~6%/y real return): Fraunhofer ISE, *Cost Perspective, Grid and Market Integration of Renewable Energies*, p 6 (Jan 2014); all sources net of subsidies; graph inspired by 2014 "Terror dome" slide, Michael Parker, Bernstein Alliance



# LED and PV



Sources: L: courtesy of Dr. Yukio Narukawa (Nichia Corp., Tokushima, Japan) from *J. Physics. D: Appl. Phys.* **43**(2010) 354002, doi:10.1088/0022-3727/43/35/354002, updated by RMI with CREE lm/W data, 2015, [www.cree.com/News-and-Events/Cree-News/Press-Releases/2014/March/300LPW-LED-barrier](http://www.cree.com/News-and-Events/Cree-News/Press-Releases/2014/March/300LPW-LED-barrier); R: RMI analysis, at average 2013 USEIA fossil-fueled generation efficiencies and each year's real fuel costs (no O&M); utility-scale PV: LBNL, *Utility-Scale Solar 2013* (Sep 2014), Fig. 18; onshore wind: USDOE, *2013 Wind Technologies Market Report* (Aug 2014), "Windbelt" (Interior zone) windfarms' average PPA; German feed-in tariff (falls with cost to yield ~6%/y real return): Fraunhofer ISE, *Cost Perspective, Grid and Market Integration of Renewable Energies*, p 6 (Jan 2014); all sources net of subsidies; graph inspired by 2014 "Terror dome" slide, Michael Parker, Bernstein Alliance



# Heresy Happens

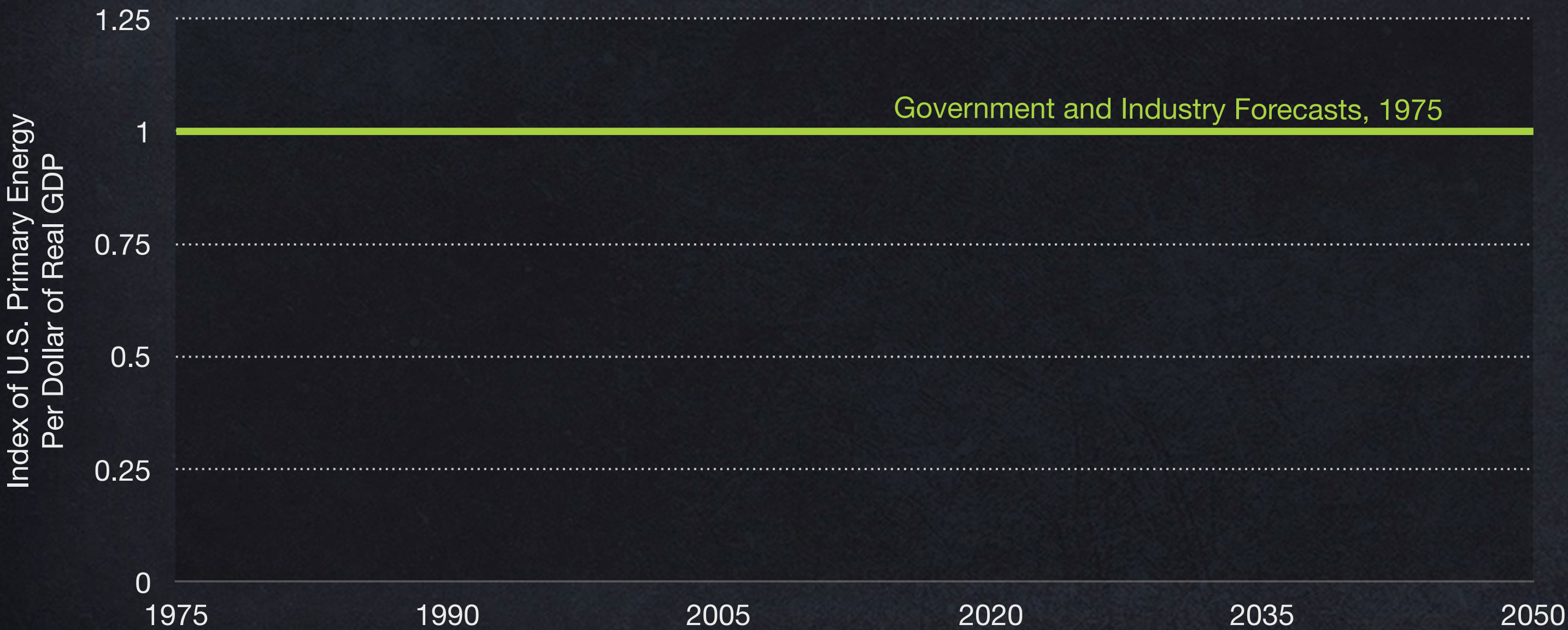
U.S. energy intensity





# Heresy Happens

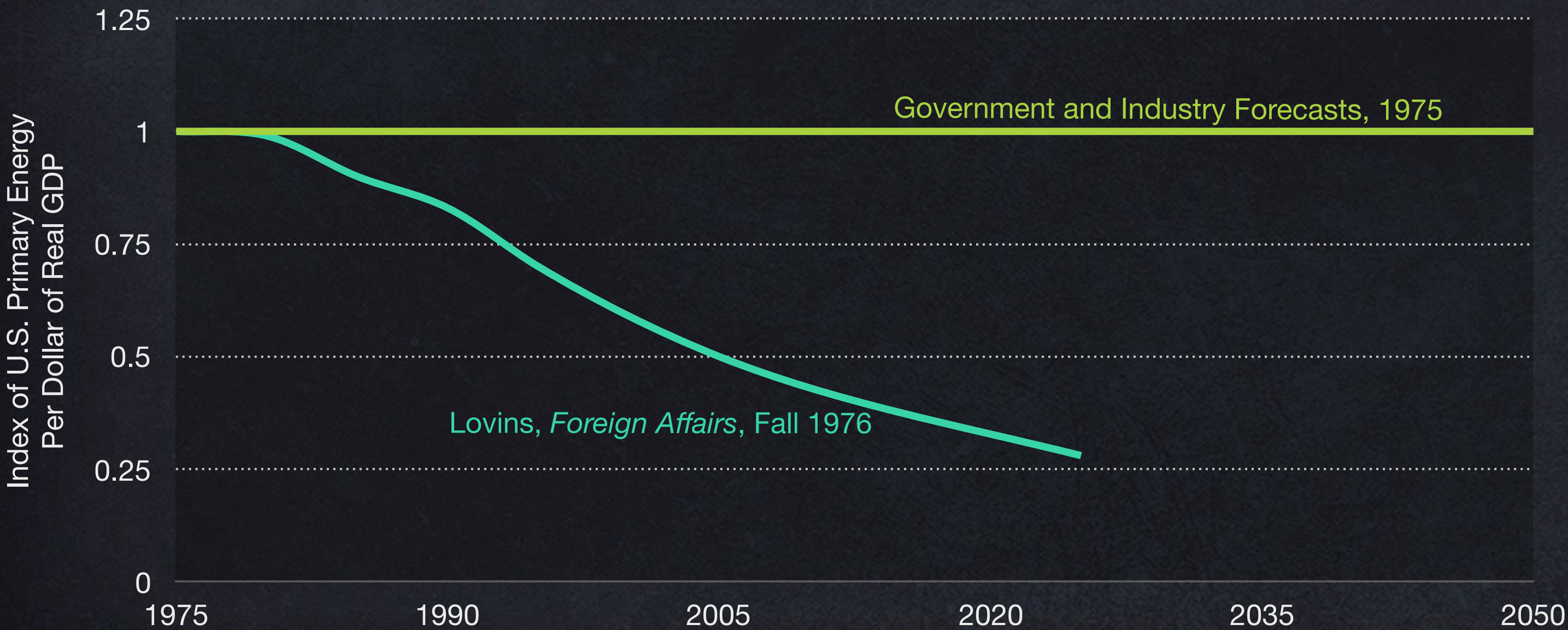
U.S. energy intensity





# Heresy Happens

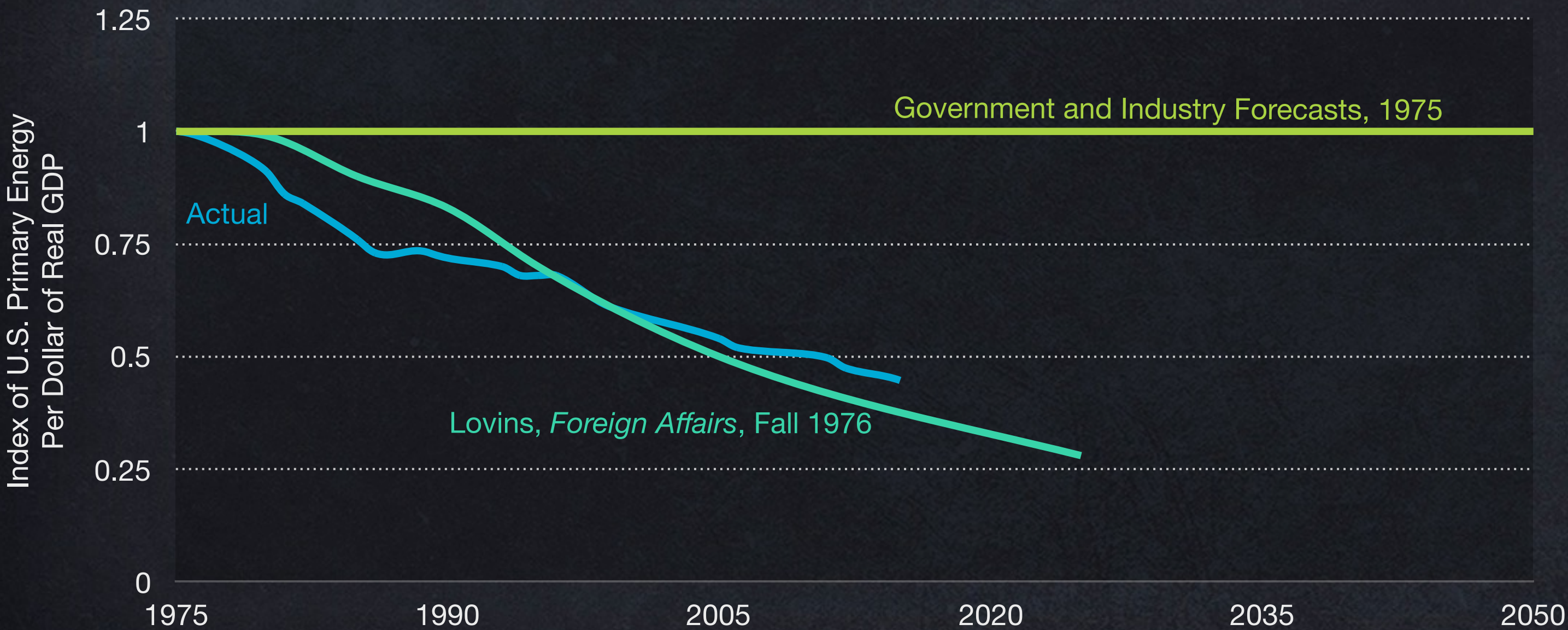
U.S. energy intensity





# Heresy Happens

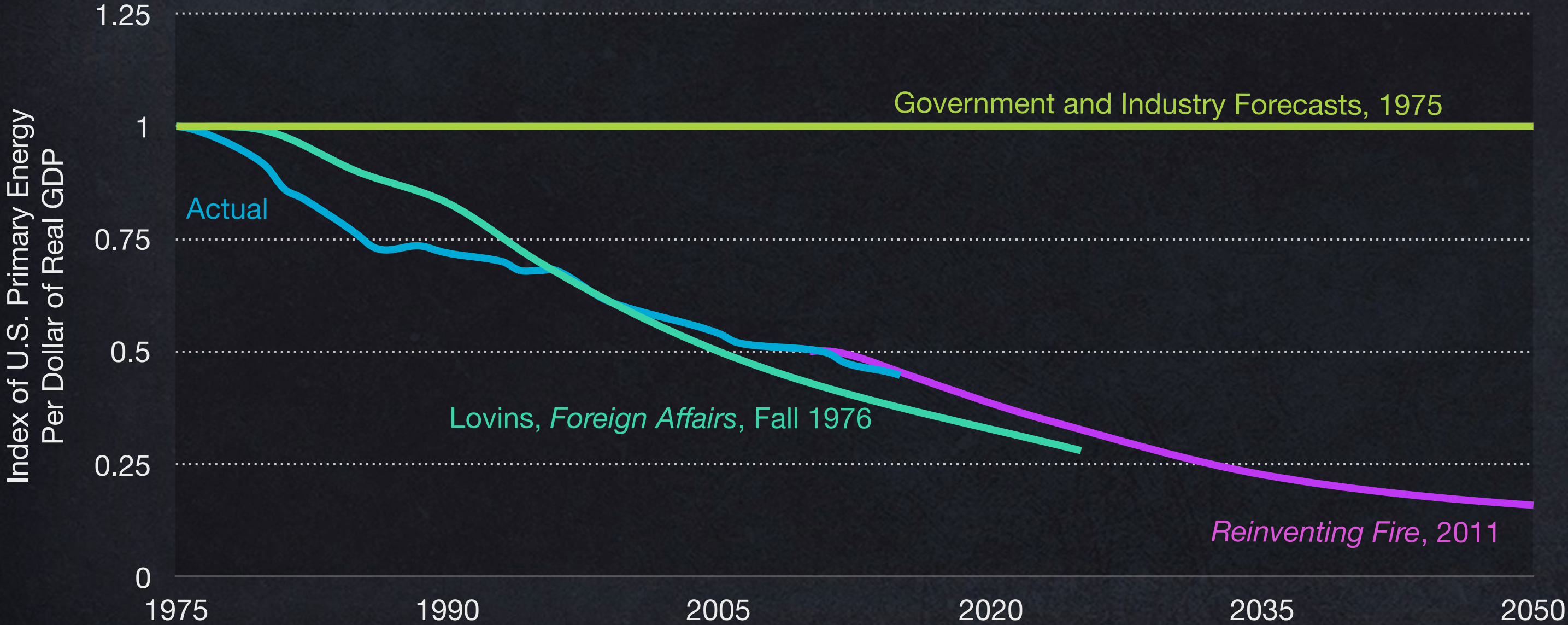
U.S. energy intensity





# Heresy Happens

U.S. energy intensity





# Lovins House, Old Snowmass, Colorado (1983)





# Lovins House, Old Snowmass, Colorado (1983)





# Lovins House, Old Snowmass, Colorado (1983)





# Lovins House, Old Snowmass, Colorado (1983)





# Lovins House, Old Snowmass, Colorado (1983)





U.S. buildings: 3–4× energy productivity worth 4× its cost  
(site energy intensities in kWh/m<sup>2</sup>-y; U.S. office median ~293)



U.S. buildings: 3–4× energy productivity worth 4× its cost  
(site energy intensities in kWh/m<sup>2</sup>-y; U.S. office median ~293)



~277 → 173 (–38%)  
2010 retrofit



U.S. buildings: 3–4× energy productivity worth 4× its cost  
(site energy intensities in kWh/m<sup>2</sup>-y; U.S. office median ~293)



~277 → 173 (–38%)	284 → 85 (–70%)
2010 retrofit	2013 retrofit



U.S. buildings: 3–4× energy productivity worth 4× its cost  
(site energy intensities in kWh/m<sup>2</sup>-y; U.S. office median ~293)



~277 → 173 (–38%)  
2010 retrofit

284 → 85 (–70%)  
2013 retrofit

... → 108 (–63%)  
2010–11 new



U.S. buildings: 3–4× energy productivity worth 4× its cost  
(site energy intensities in kWh/m<sup>2</sup>-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



U.S. buildings: 3–4× energy productivity worth 4× its cost  
(site energy intensities in kWh/m<sup>2</sup>-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

*Yet all the technologies in the 2015 example existed well before 2005!*



# 80% energy savings in Hyderabad office, lower capex



Infosys DSB1 (2009): world's largest side-by-side HVAC experiment  
Radiant side (11,152 m<sup>2</sup>): 66 kWh/m<sup>2</sup>-y (-80%), capex -9%



# BAM's unsubsidized mass retrofit of Dutch public housing



Before: 5 units, each with annual energy bills ~€1.5–2k



After: net-zero-energy, expected to be financed just from energy savings by industrializing the €40–60k/unit retrofit









# Radical Efficiency

motors, pumps, *and* pipes





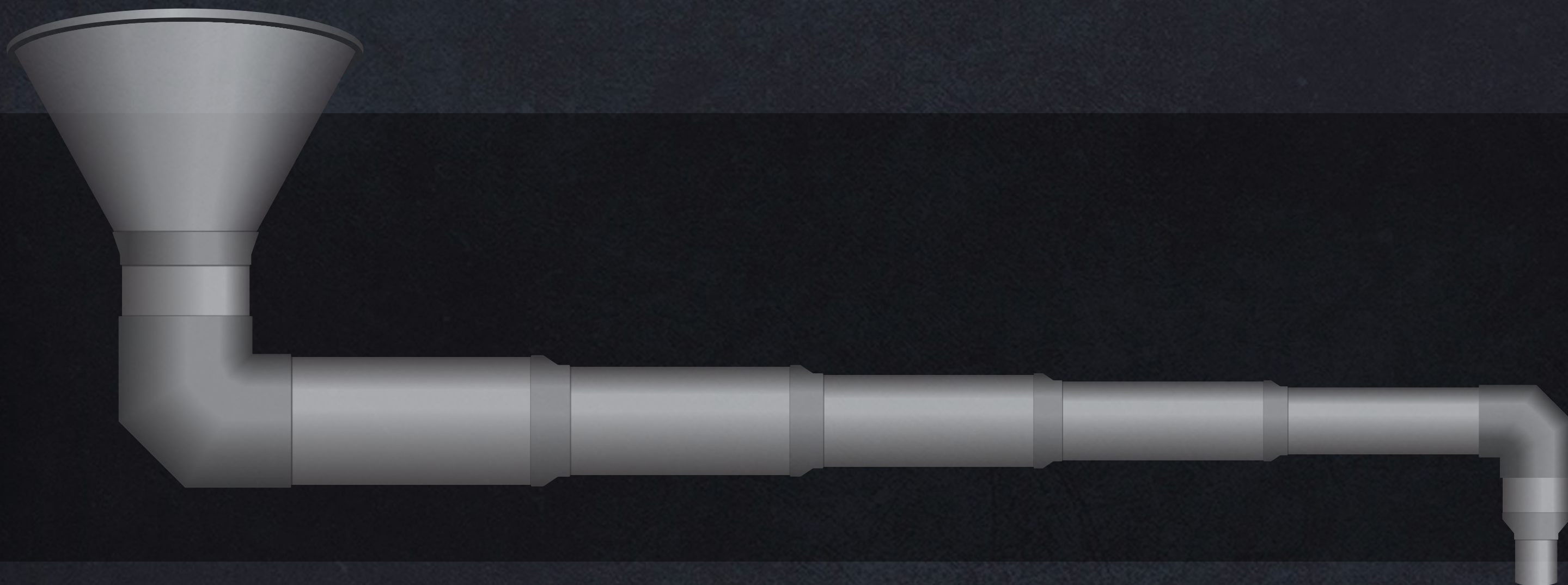


# Less Capital Investment

smaller equipment



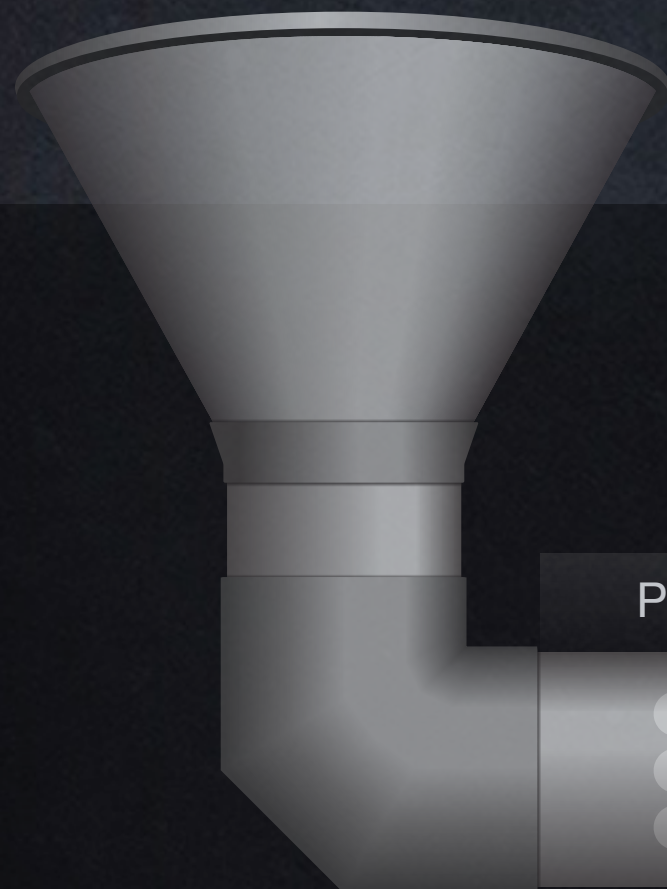








100  
Energy units



-70%

Power Plant

-9%

Power Grid

-12%

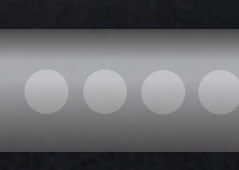
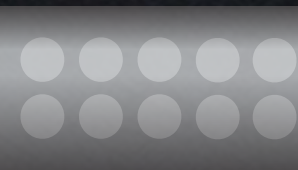
Motor/Drivetrain

-55%

Pump/Throttle

-20%

Pipe

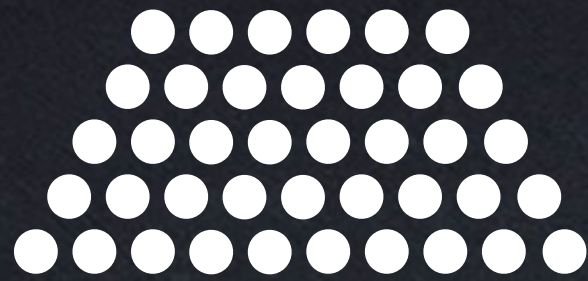


10%

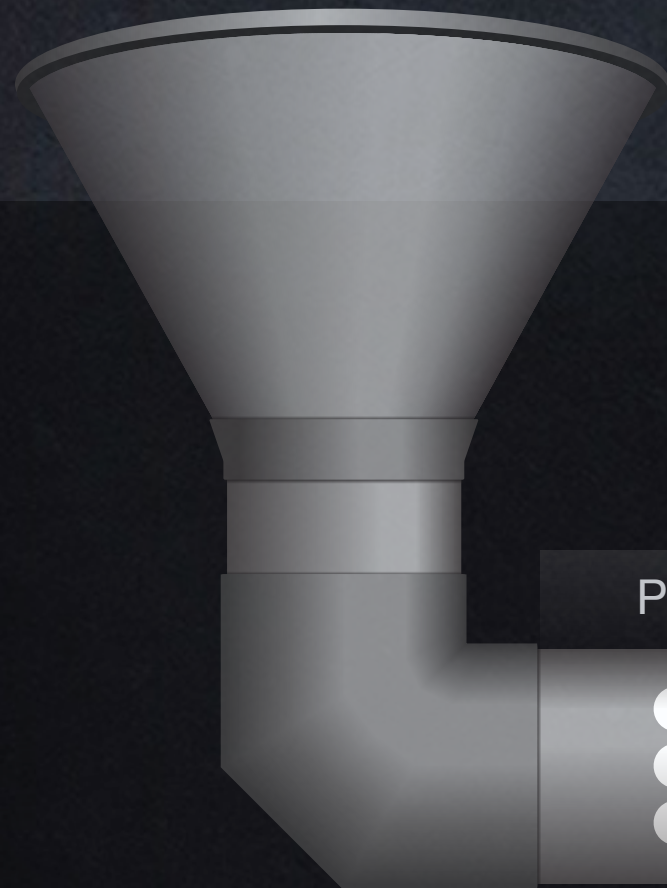
Delivered flow





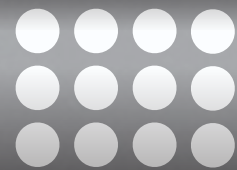


100  
Energy units



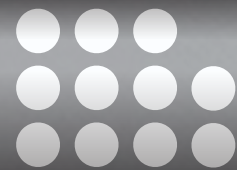
-70%

Power Plant



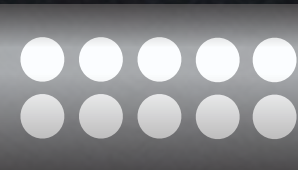
-9%

Power Grid



-12%

Motor/Drivetrain



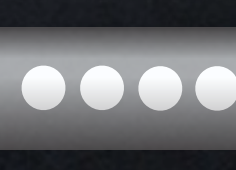
-55%

Pump/Throttle



-20%

Pipe

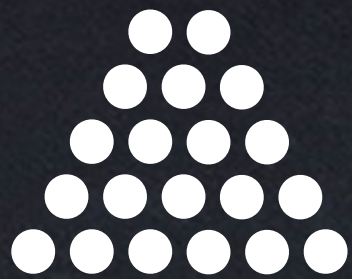


5%

Delivered flow







50  
Energy units

-70%

Power Plant



-9%

Power Grid



-12%

Motor/Drivetrain



-55%

Pump/Throttle



-20%

Pipe



5%

Delivered flow











radically efficient industrial redesign







# Netherlands: community connection

Stap 1: jouw situatie

Maak een schatting van je verbruik: ?

Rijthuis

3 bewoners

Of vul je verbruik zelf in: ?

Ik heb een enkele meter

Elektriciteit: 2850 kWh

Gas: 1200 m<sup>3</sup>

soorten bronnen: Wind Water Bio Zon

50 Beschikbaar

Bespaar €2,44 per maand \*

€44,74 per mnd

1 Beschikbaar

Bespaar €0,00 per maand \*

€51,67 per mnd

131 Beschikbaar

Bespaar €3,03 per maand \*

€44,15 per mnd

Biovergister van Gerard Oude Lenferink, FLERINGEN

6 Beschikbaar

Bespaar €3,02 per maand \*

€44,17 per mnd

Windenergie van Gerard en Monique, LELYSTAD

2 Beschikbaar

Bespaar €2,73 per maand \*

€44,46 per mnd

Windenergie van Jaap en Feikje, MOLKWERUM

0 Beschikbaar

Bespaar €2,73 per maand \*

€44,46 per mnd

Windenergie van Wim Fokkema, ZEEWOLDE

0 Beschikbaar

Bespaar €2,73 per maand \*

€44,46 per mnd

Zonnepark Azewijn, AZEWIJN

0 Beschikbaar

Bespaar €1,87 per maand \*

€45,32 per mnd

Windenergie van Gorrit Jansen, St. Annaparochie

0 Beschikbaar

Bespaar €1,58 per maand \*

€45,61 per mnd





Utility revenues



Efficiency



Utility revenues



Distributed  
renewables



Integrative  
design



Customer  
preferences

Efficiency

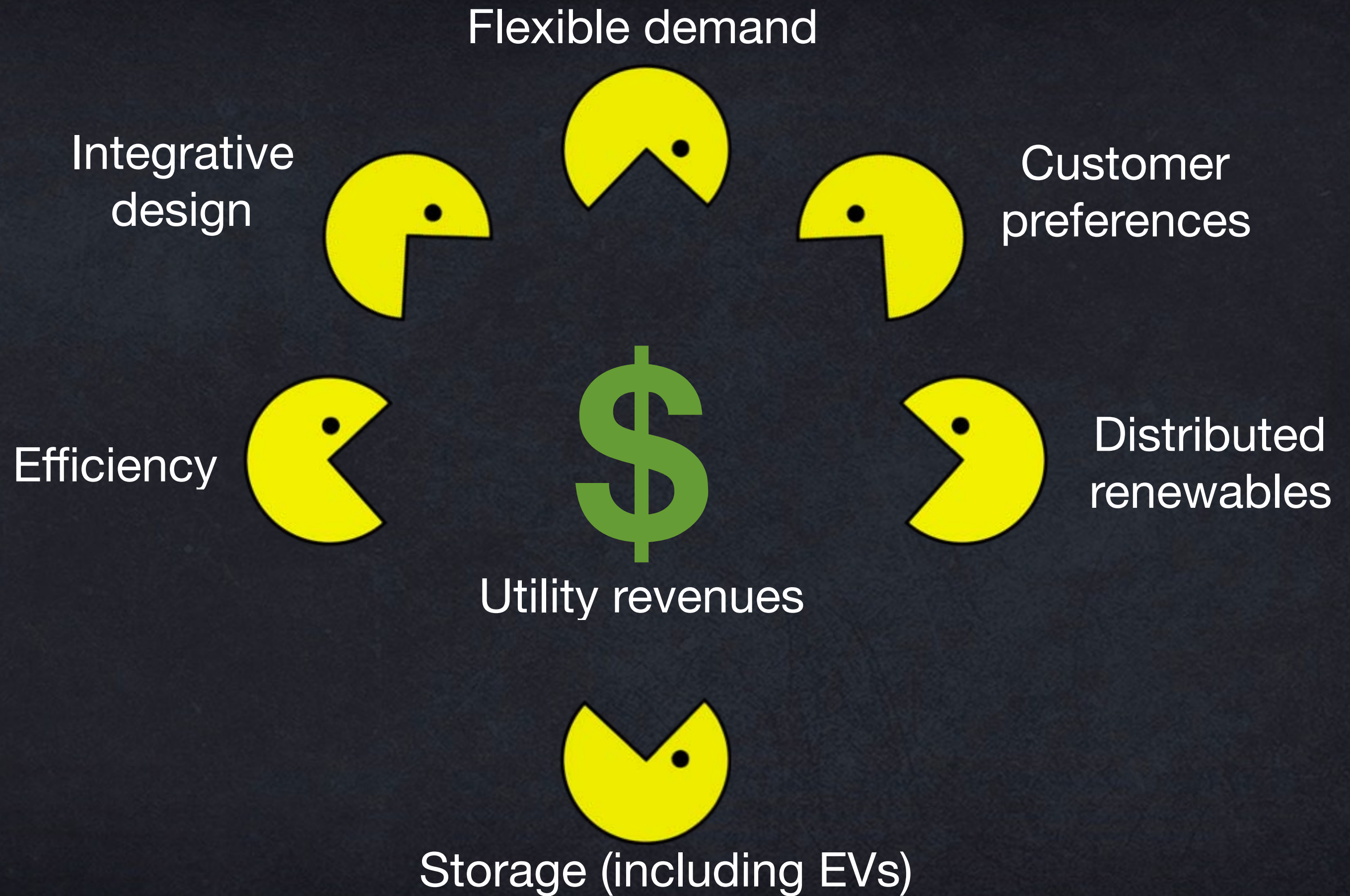


Utility revenues

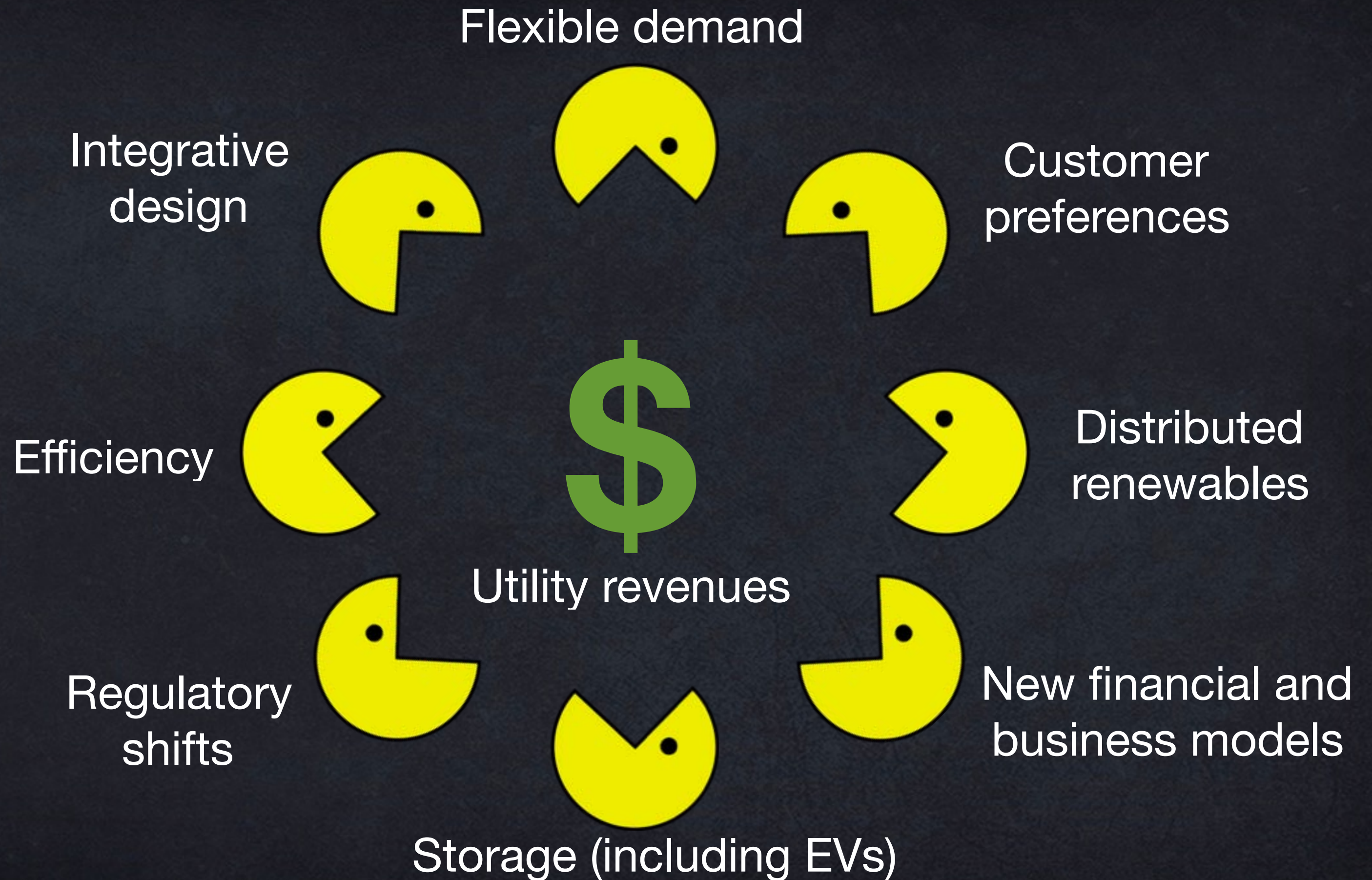


Distributed  
renewables













Utility revenues



Integrative  
design



Efficiency

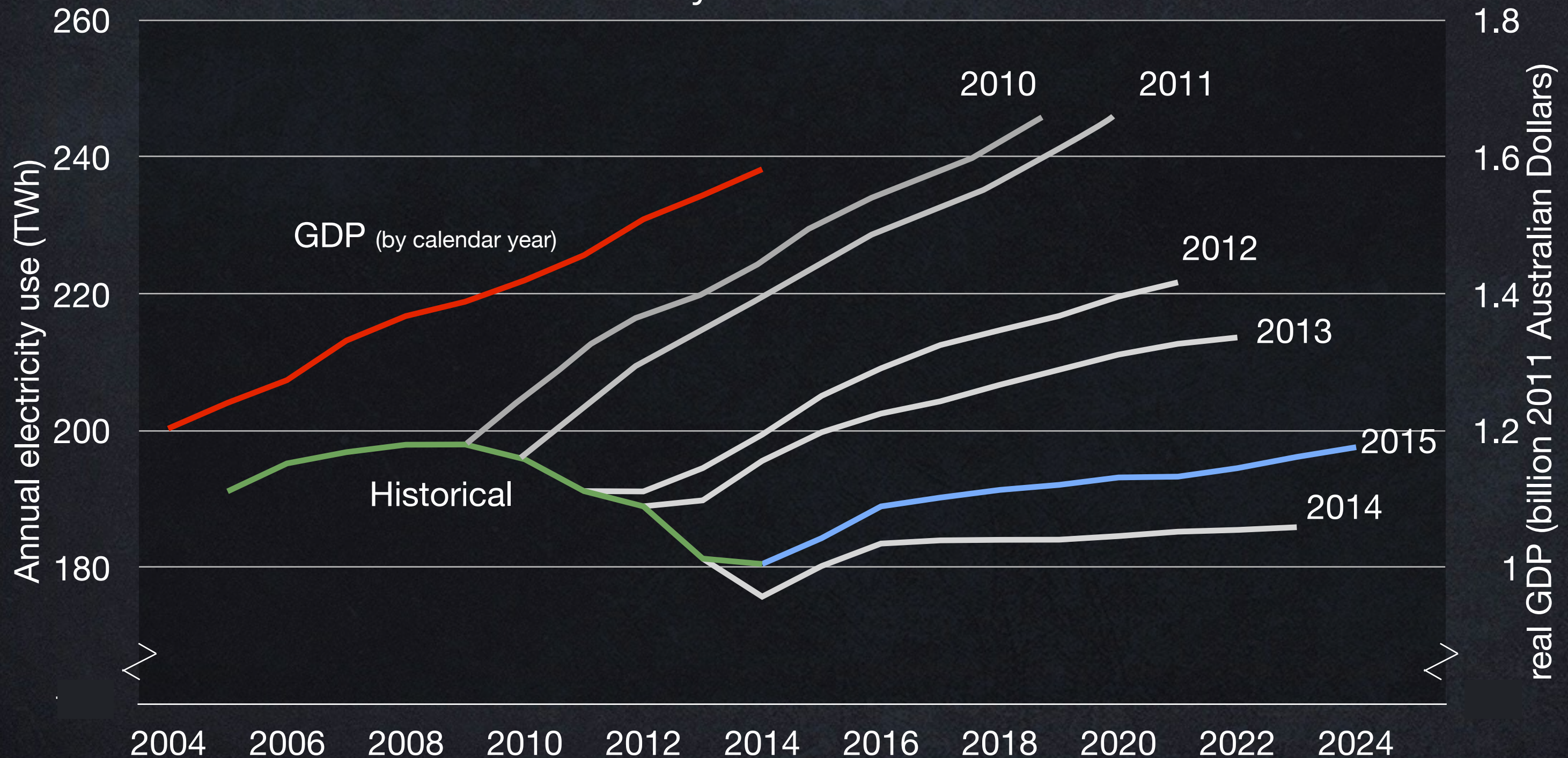


Utility revenues



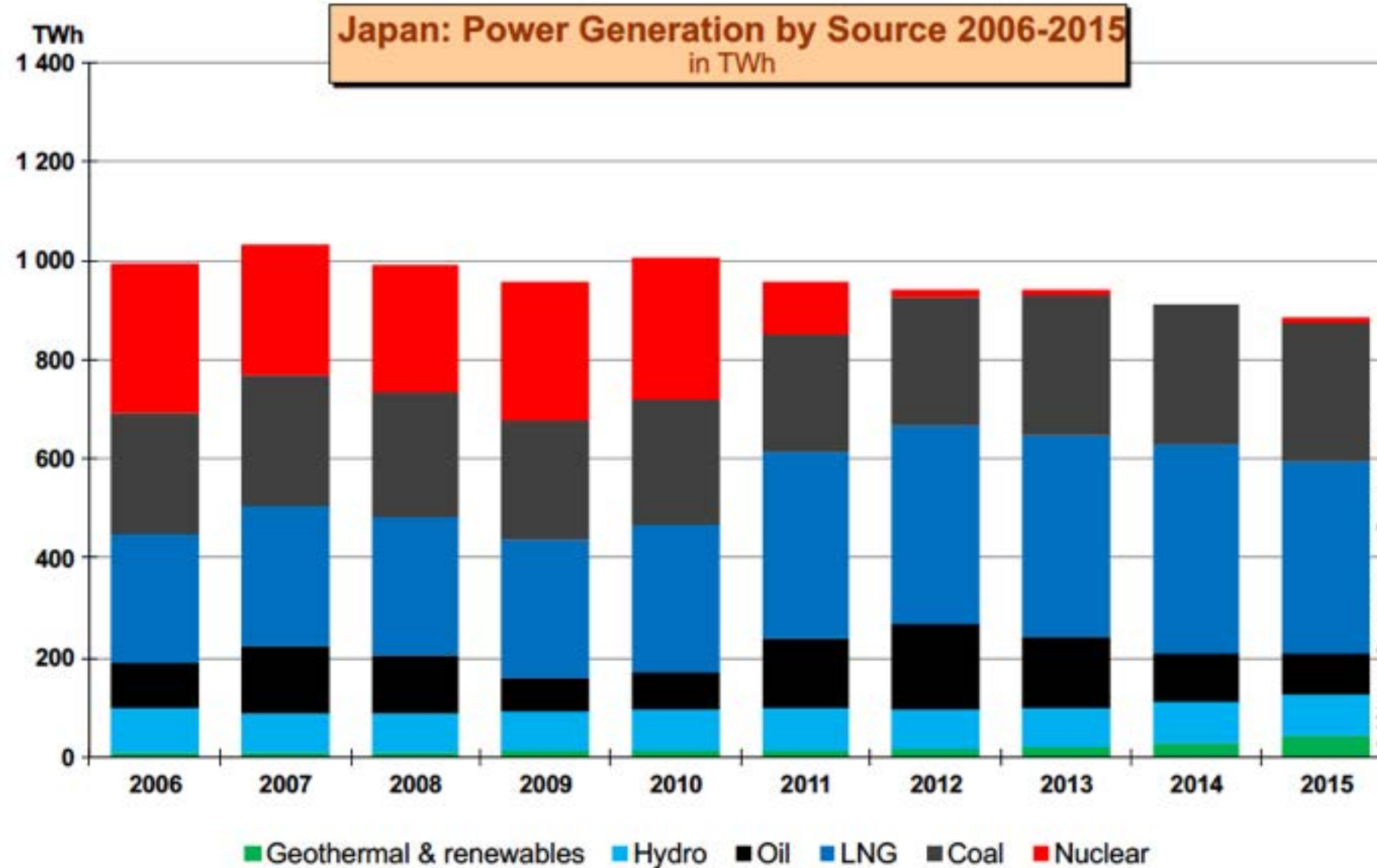
# Australia national electricity market

Actual vs. forecast electricity demand





# Japan replaced 56% of nuclear loss with savings\* and renewables in 2010–2015



Source: FEPC, "Summary of Press Conference Comments Made by Makoto Yagi, FEPC Chairman, on 20 May 2016"

MYCLE SCHNEIDER CONSULTING

Tokyo, 13 July 2016

\*The reduced demand includes technical efficiency, behavioral change, and some distributed generation or cogeneration from natural gas, forest wastes, solar power, etc. in industry and in big buildings. Such sources are not yet well measured in Japan, but their total output is material and rising.





Utility revenues





Utility revenues



Distributed  
renewables



Flexible demand



Utility revenues



Distributed  
renewables



Storage (including EVs)



# Renewable Energy’s Costs Continue to Plummet

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

levelized 2014 US\$/MWh

x



# Renewable Energy's Costs Continue to Plummet

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



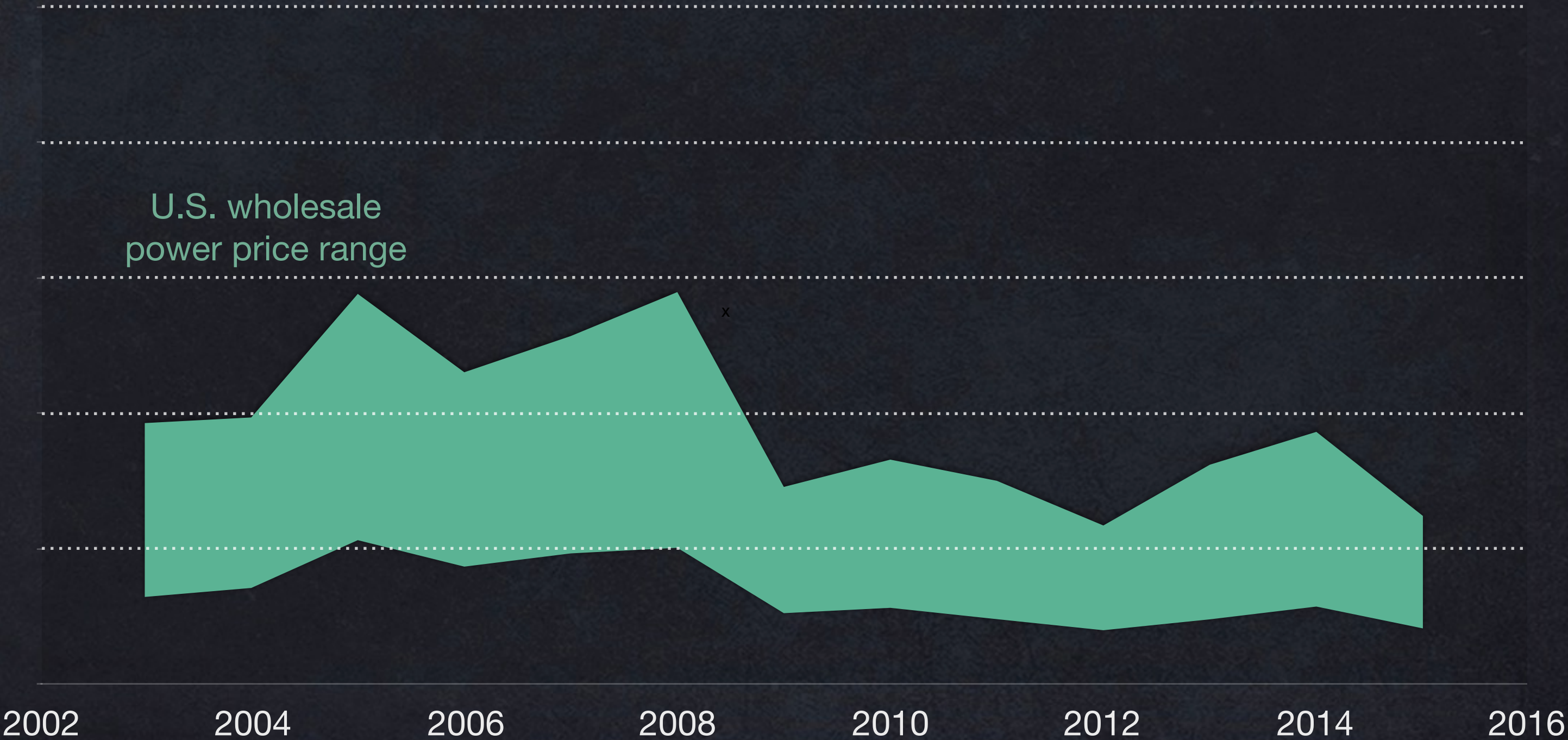


# Renewable Energy's Costs Continue to Plummet

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

levelized 2014 US\$/MWh

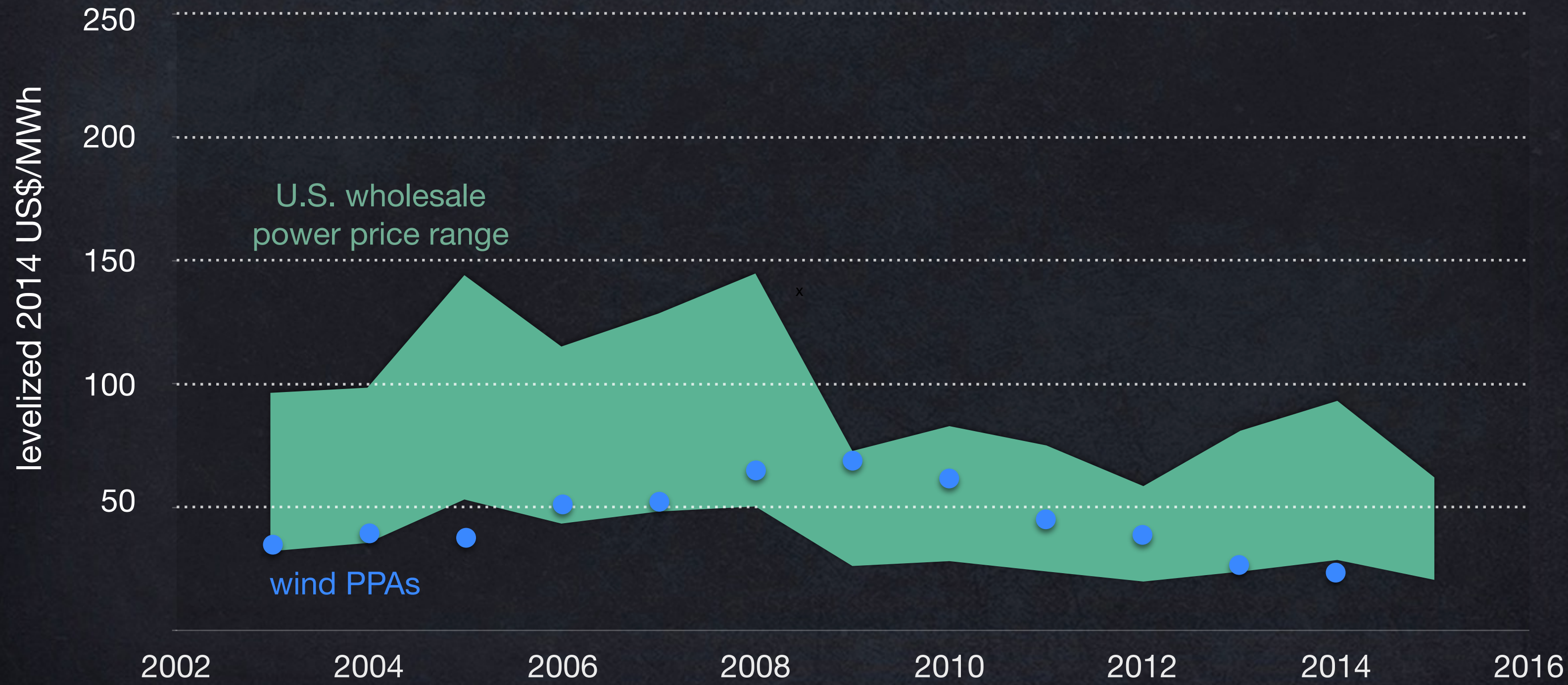
U.S. wholesale  
power price range





# Renewable Energy's Costs Continue to Plummet

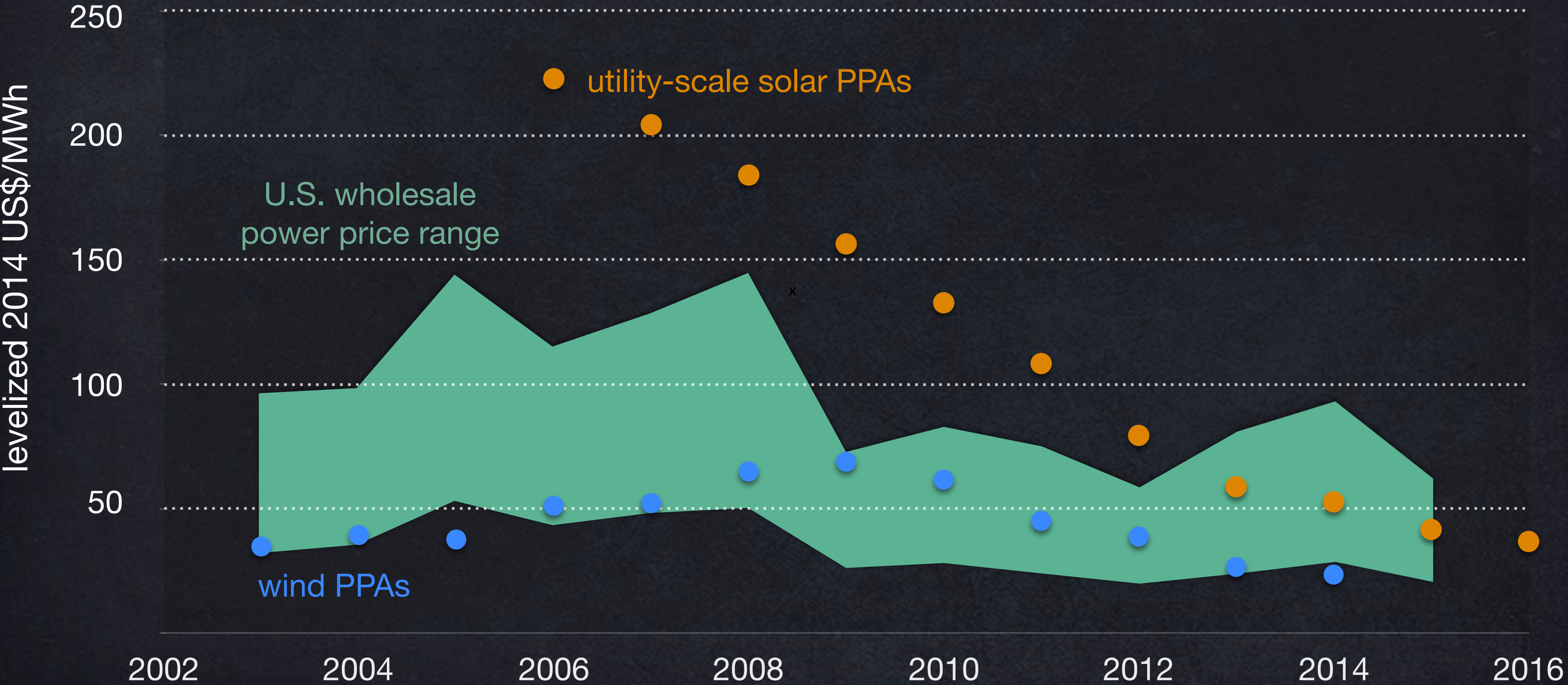
Wind and photovoltaics: U.S. generation-weighted-average Power Purchase Agreement prices, by year of signing





# Renewable Energy's Costs Continue to Plummet

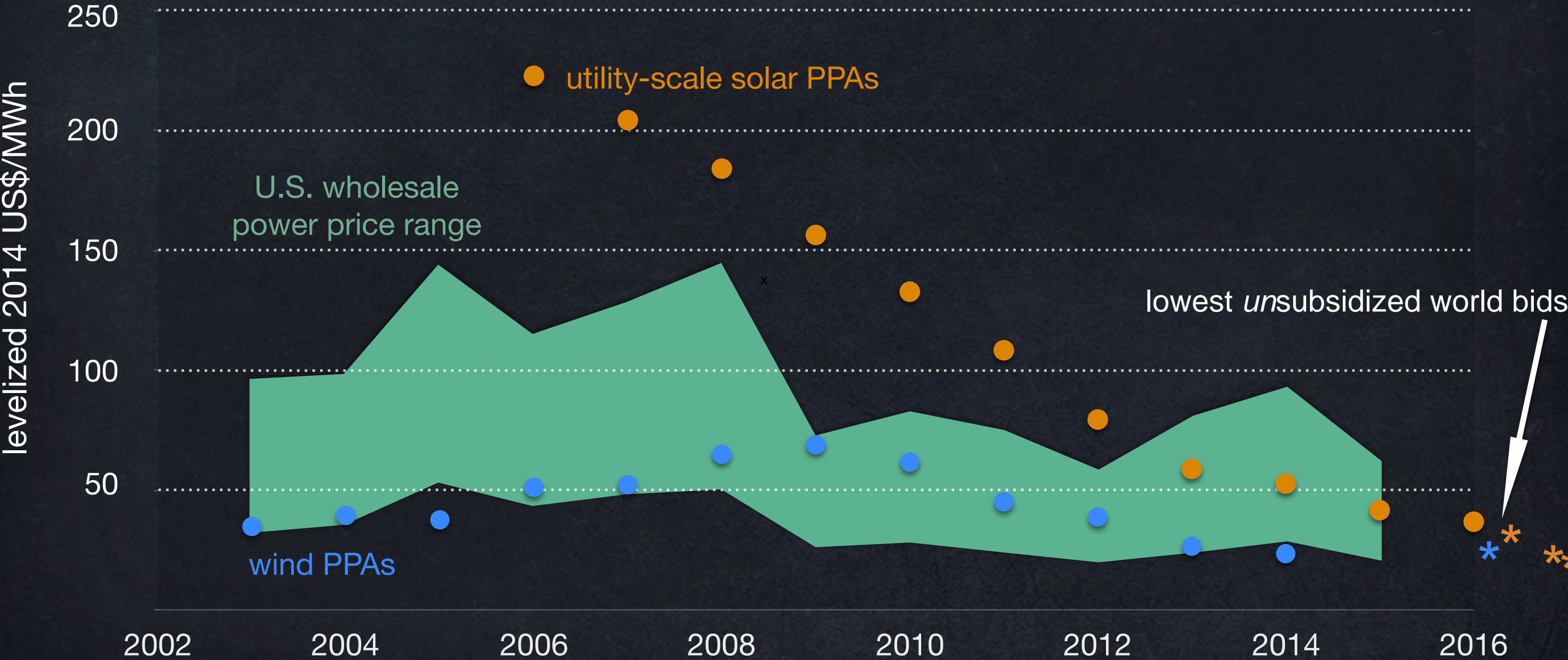
Wind and photovoltaics: U.S. generation-weighted-average Power Purchase Agreement prices, by year of signing





# Renewable Energy's Costs Continue to Plummet

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





# Best resources far away, or adequate resources nearby?

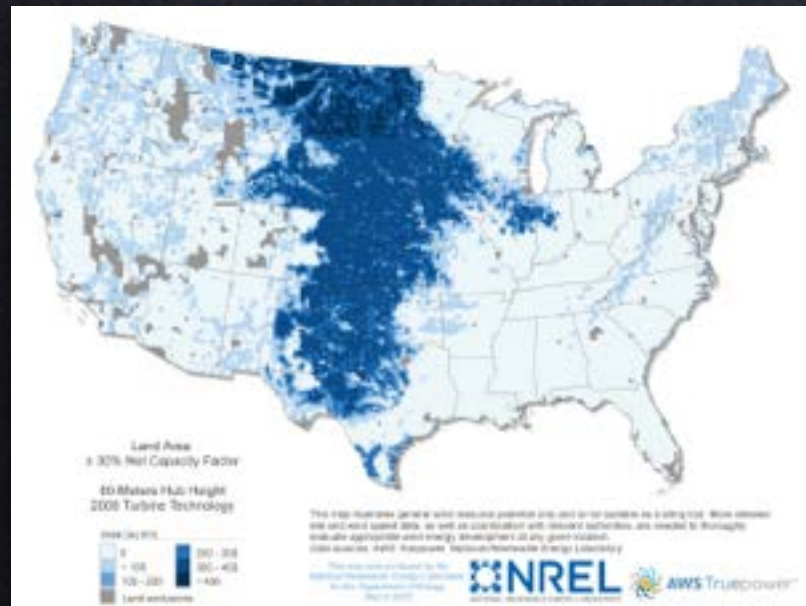
## 舍近求远还是就地取材

2008

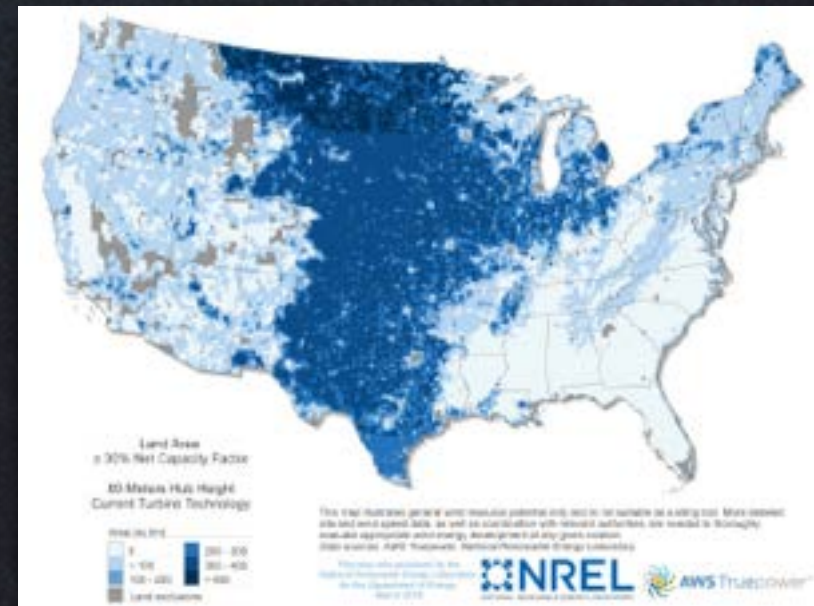
2013

2013

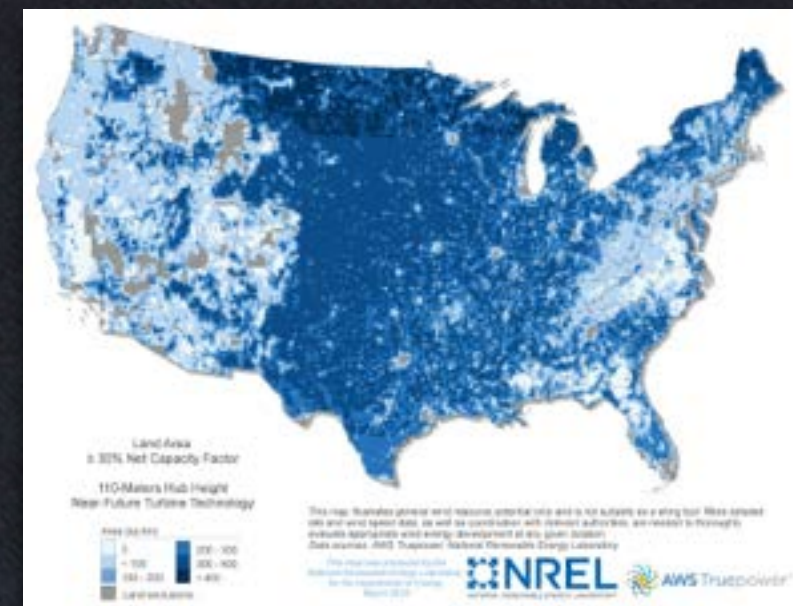
2015



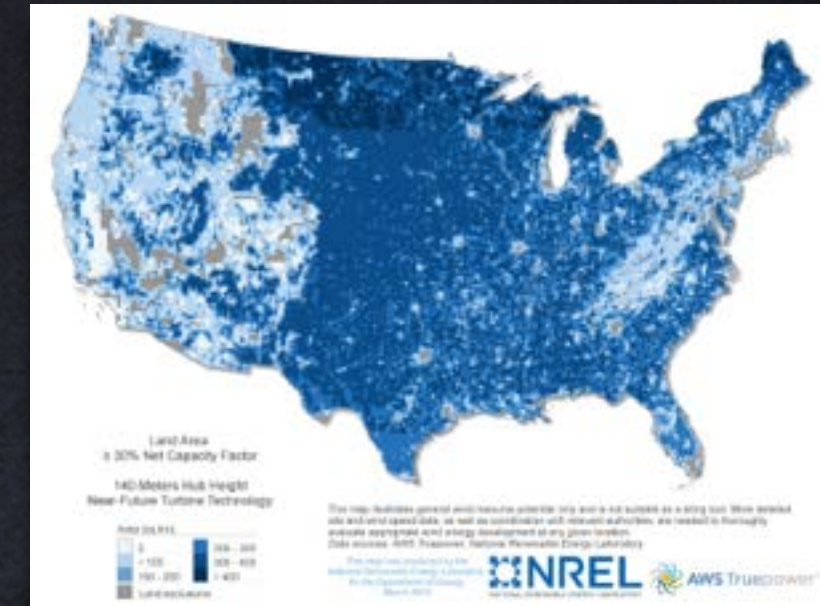
400 W/m<sup>2</sup>, 80m



210–320 W/m<sup>2</sup>, 80m



150 W/m<sup>2</sup>, 110m



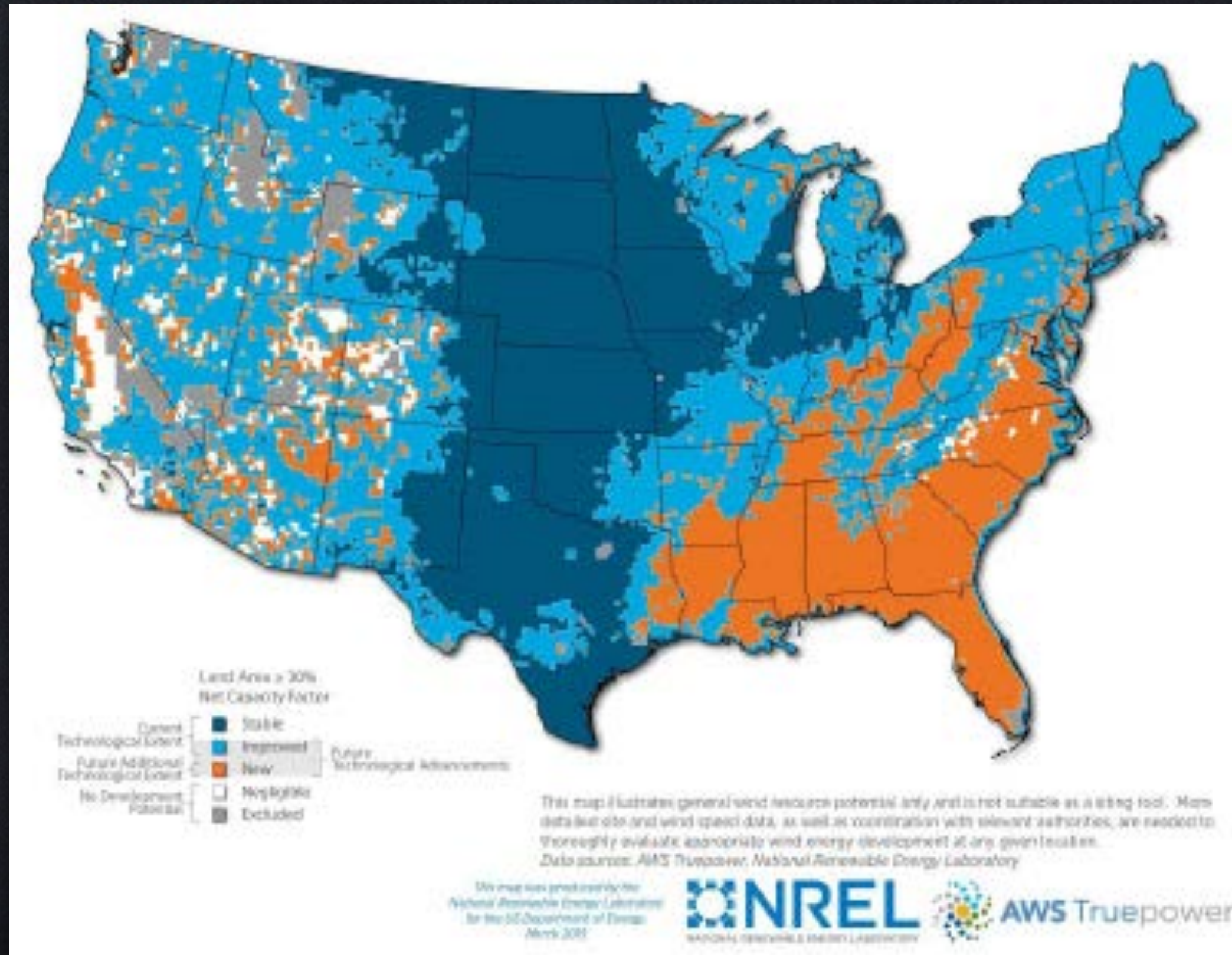
150 W/m<sup>2</sup>, 140m

## 2008–15: TWh/y +67%



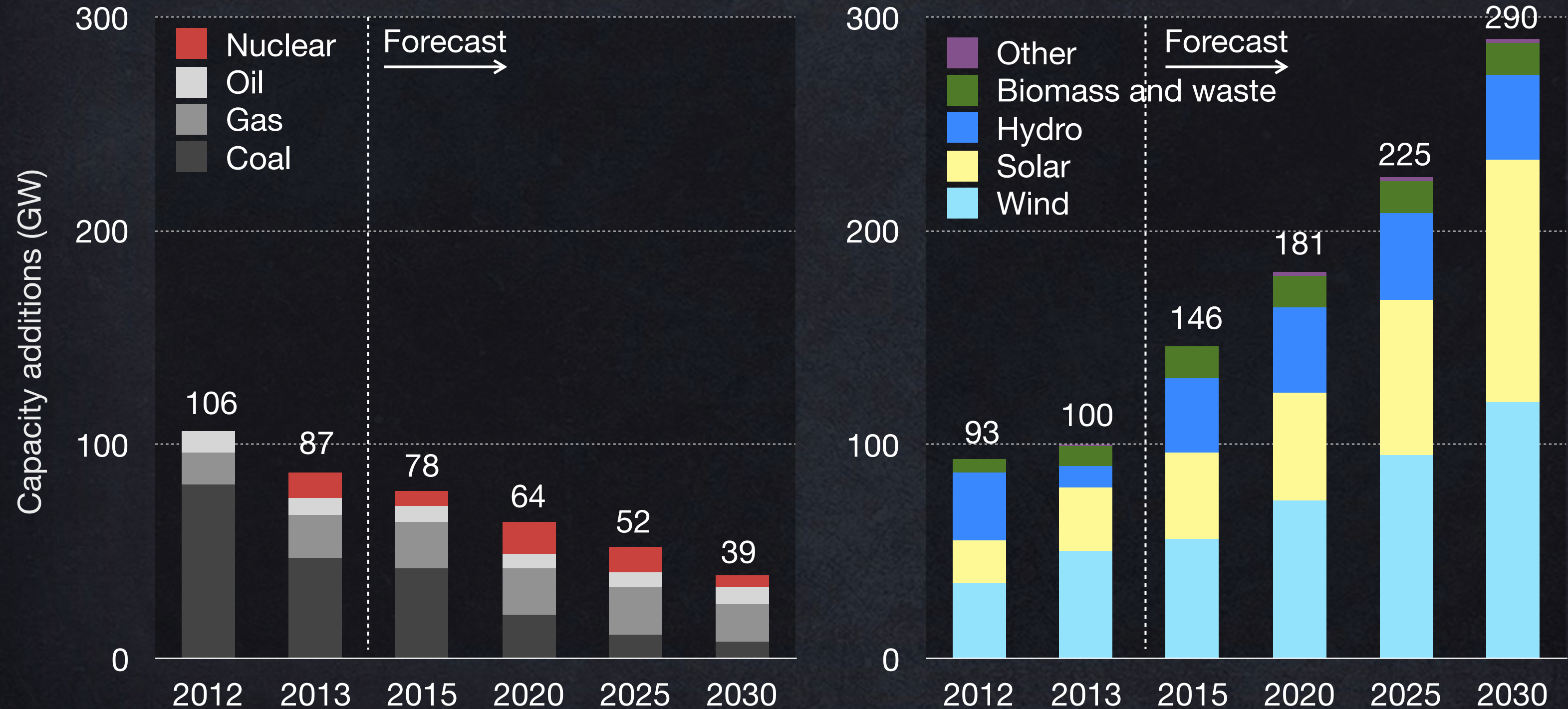
# Best resources far away, or adequate resources nearby?

## 舍近求远还是就地取材





# Global power generation capacity additions, 2012–30



Source: Bloomberg New Energy Finance, redrawn from Michael Liebreich's Summit Keynote, 7 April 2014





0 GW-y

“Cathedral”

Photovoltaics

0 GW-y



Years

00





3 GW-y

“Cathedral”



Photovoltaics

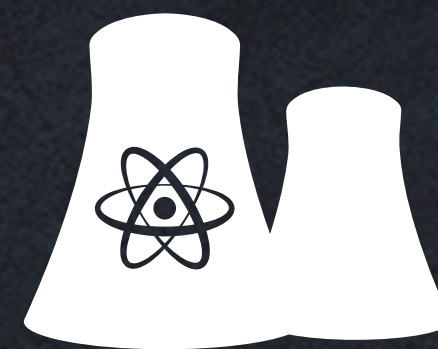
45 GW-y



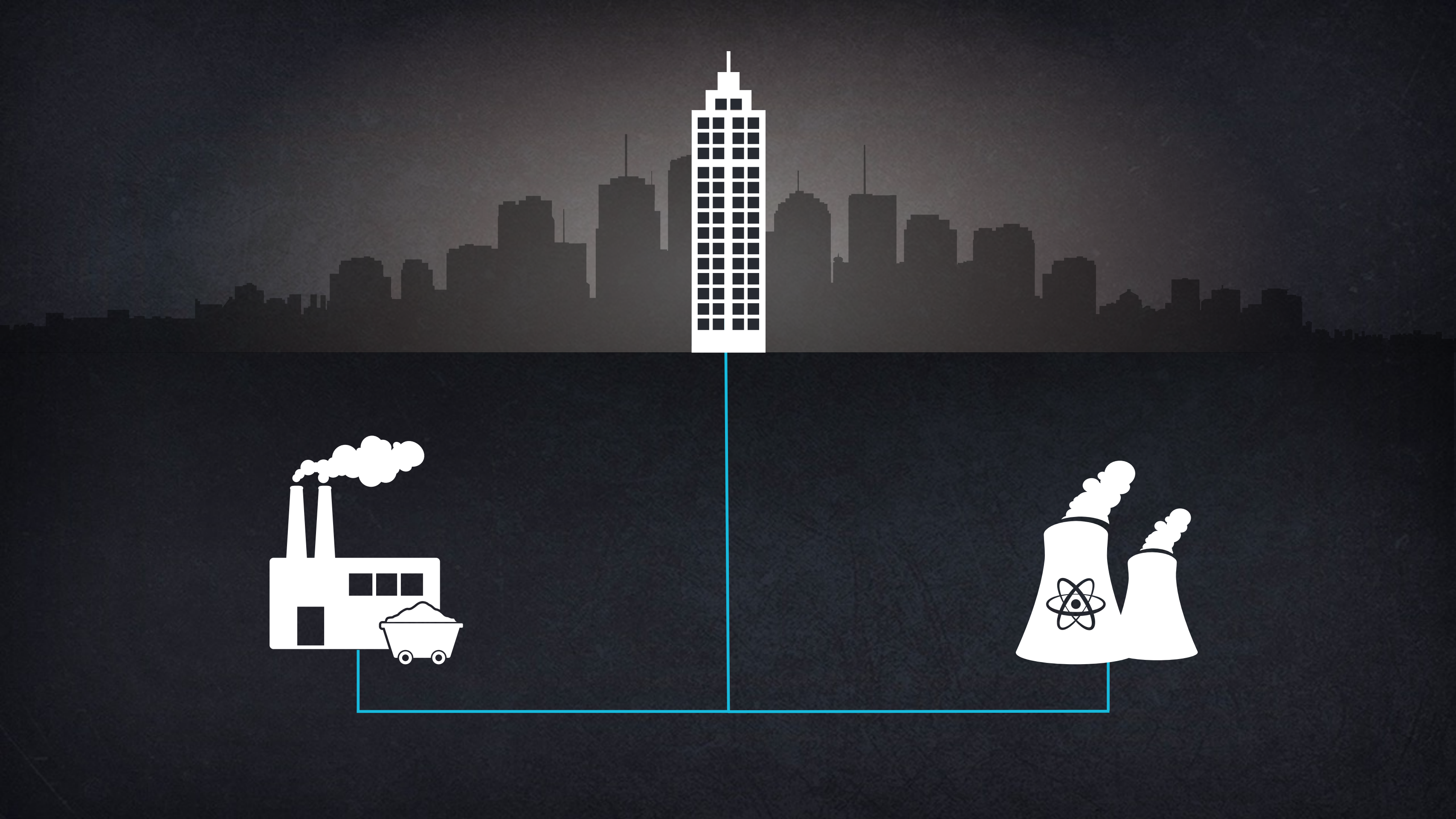
Years

10











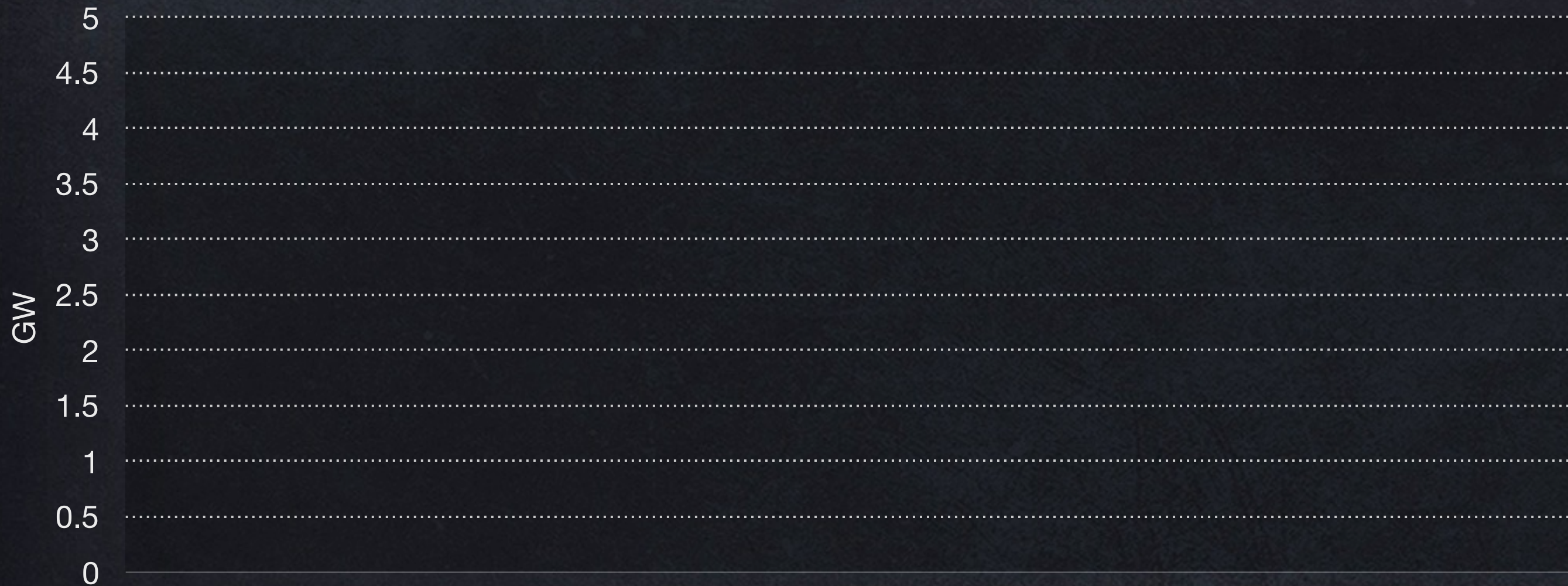
# Variable Renewables Can Be Forecasted At Least as Accurately as Electricity Demand

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



# Variable Renewables Can Be Forecasted At Least as Accurately as Electricity Demand

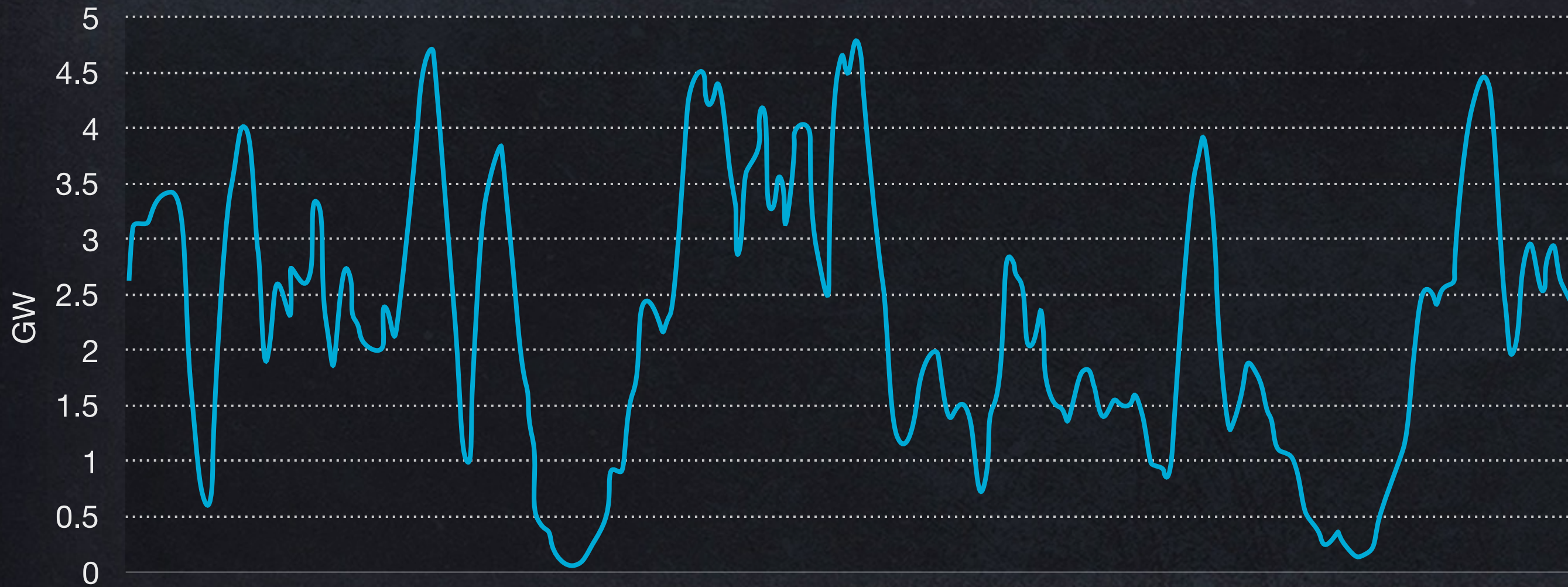
French windpower output, December 2011: **forecasted one day ahead** vs. **actual**





# Variable Renewables Can Be Forecasted At Least as Accurately as Electricity Demand

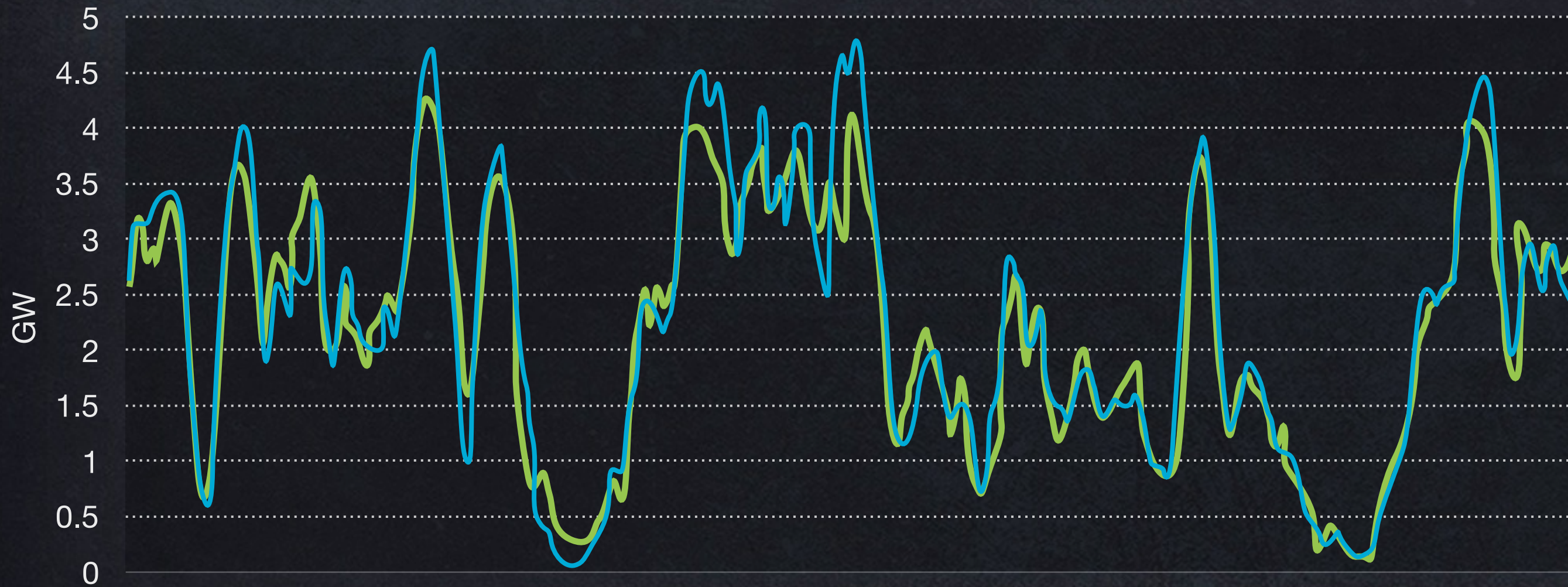
French windpower output, December 2011: **forecasted one day ahead** vs. **actual**





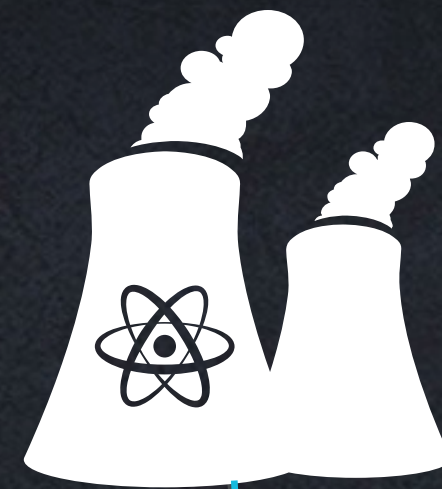
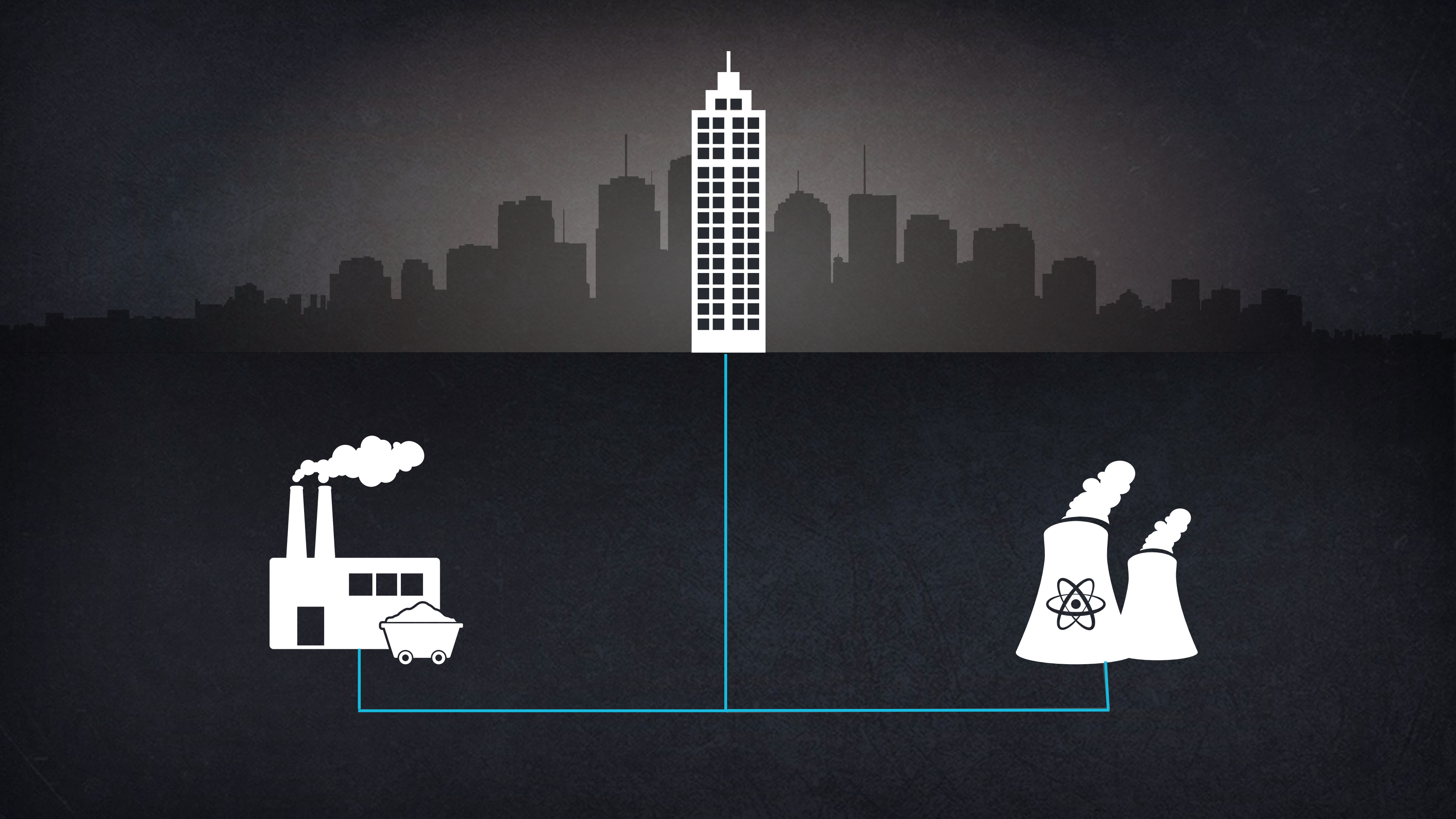
# Variable Renewables Can Be Forecasted At Least as Accurately as Electricity Demand

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









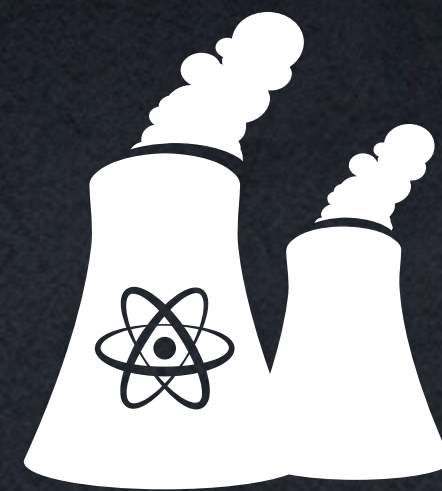




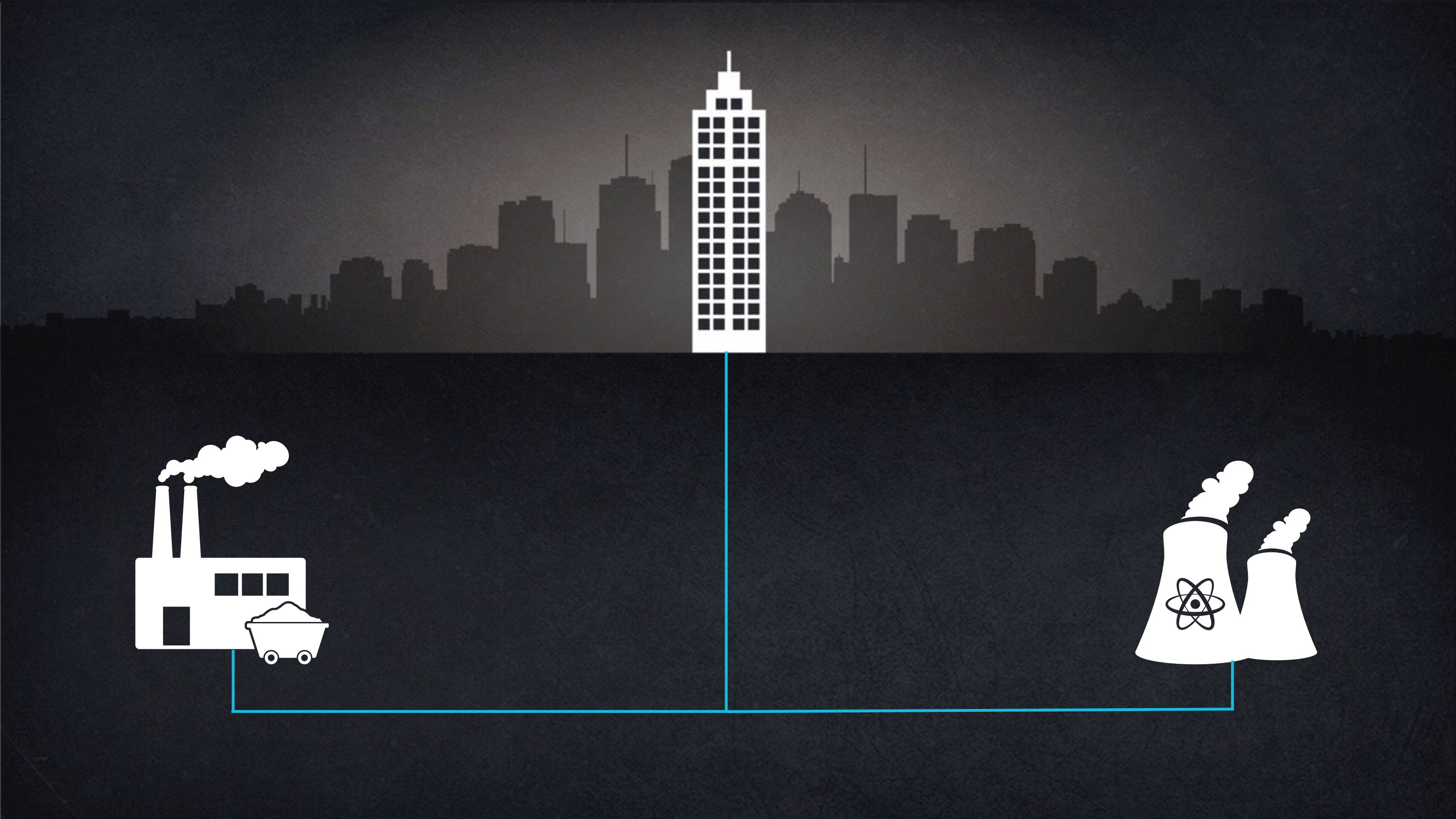




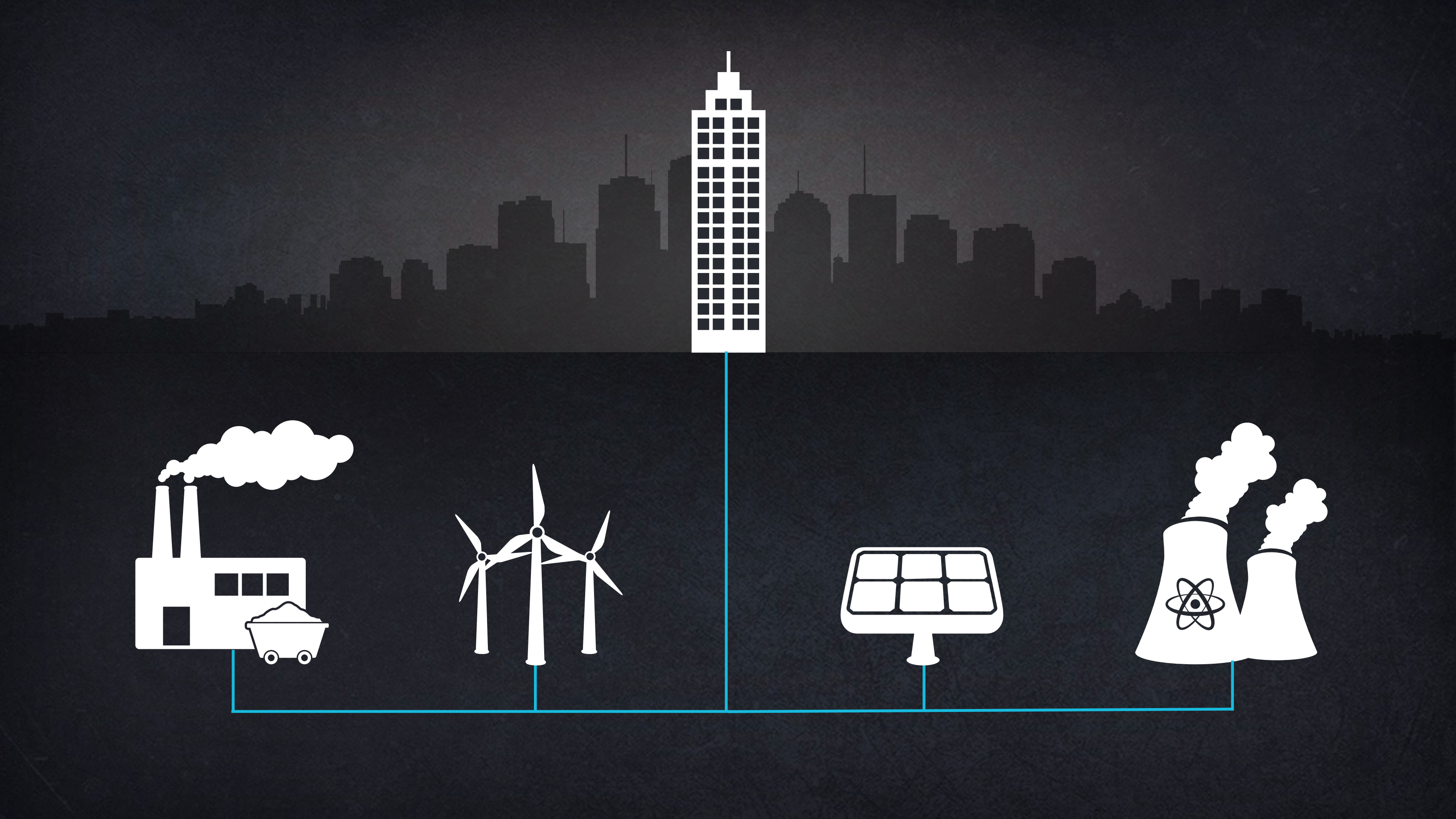














# Choreographing Variable Renewable Generation

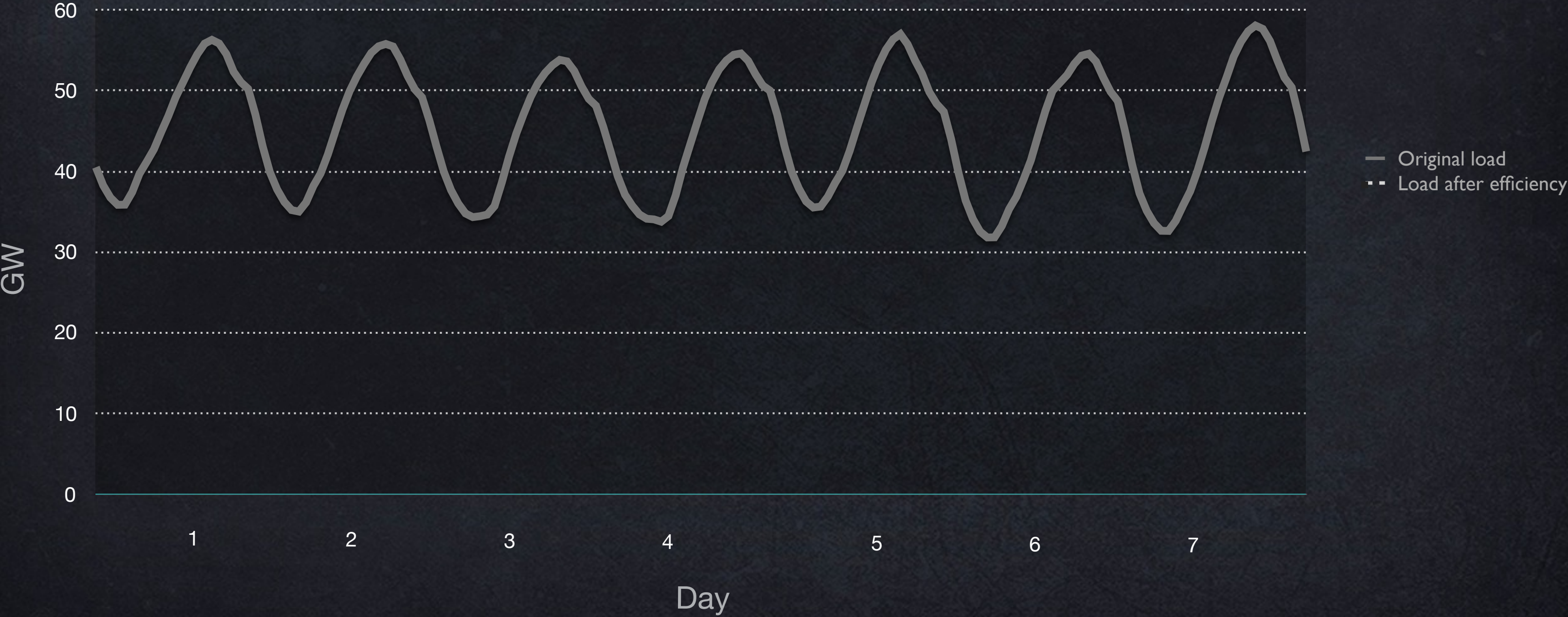
ERCOT power pool, Texas summer week, 2050 (RMI hourly simulation)





# Choreographing Variable Renewable Generation

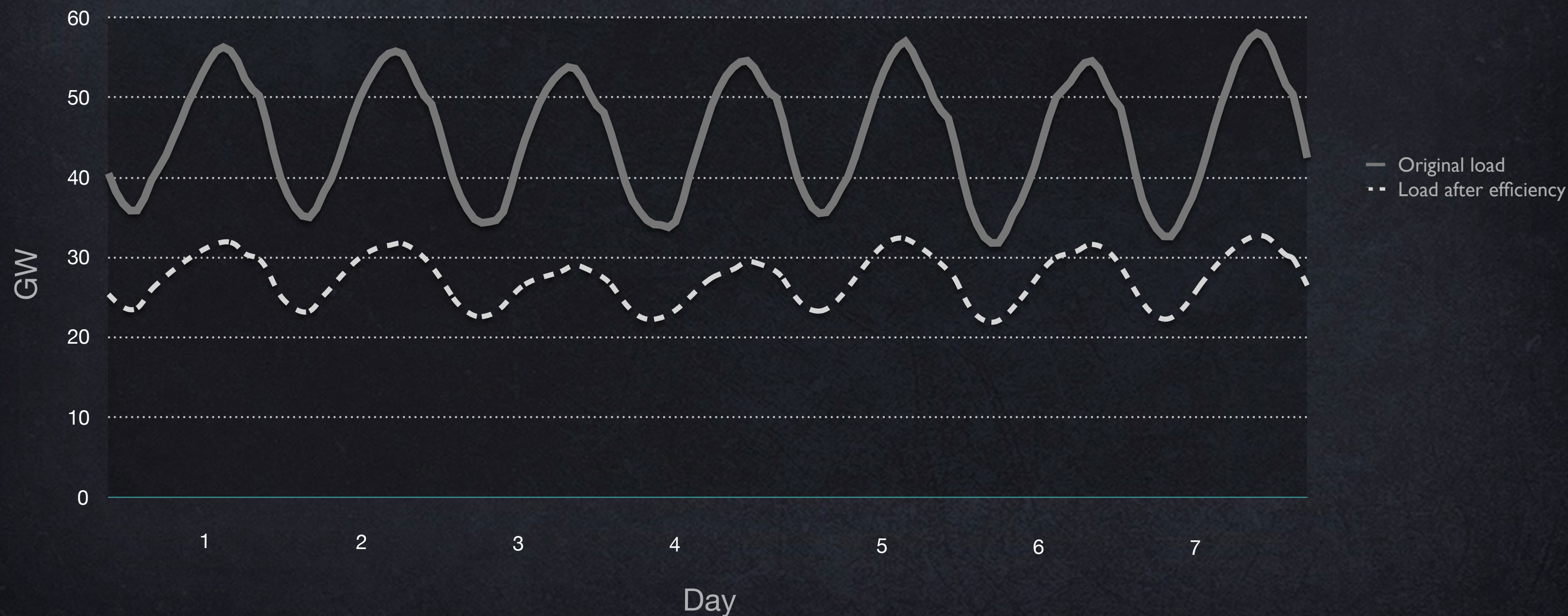
ERCOT power pool, Texas summer week, 2050 (RMI hourly simulation)





# Choreographing Variable Renewable Generation

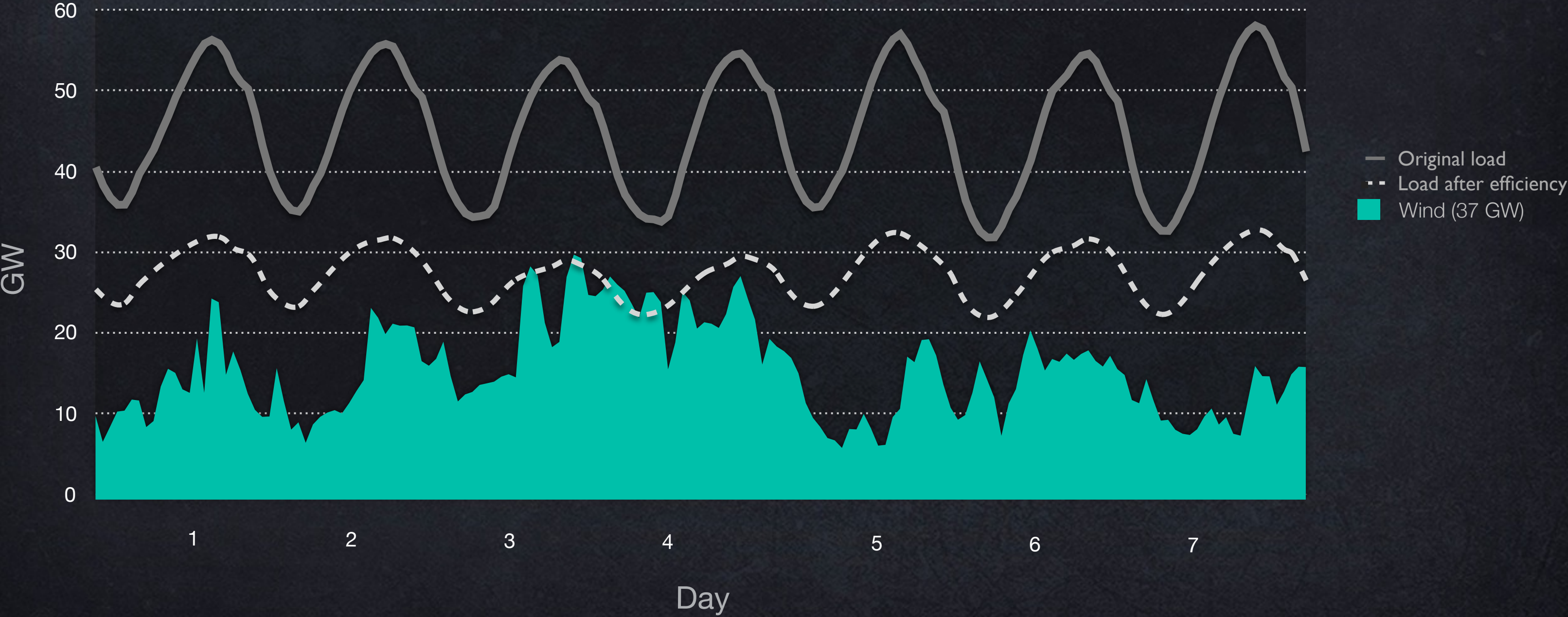
ERCOT power pool, Texas summer week, 2050 (RMI hourly simulation)





# Choreographing Variable Renewable Generation

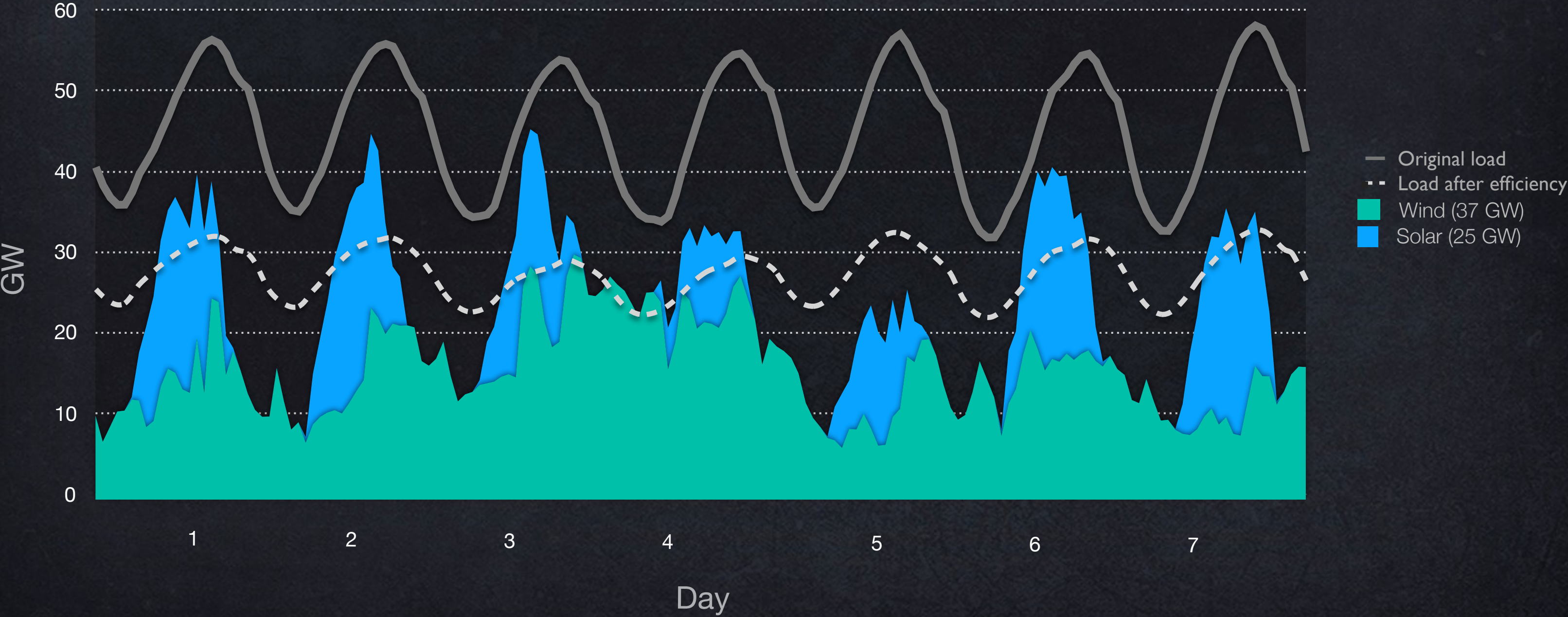
ERCOT power pool, Texas summer week, 2050 (RMI hourly simulation)





# Choreographing Variable Renewable Generation

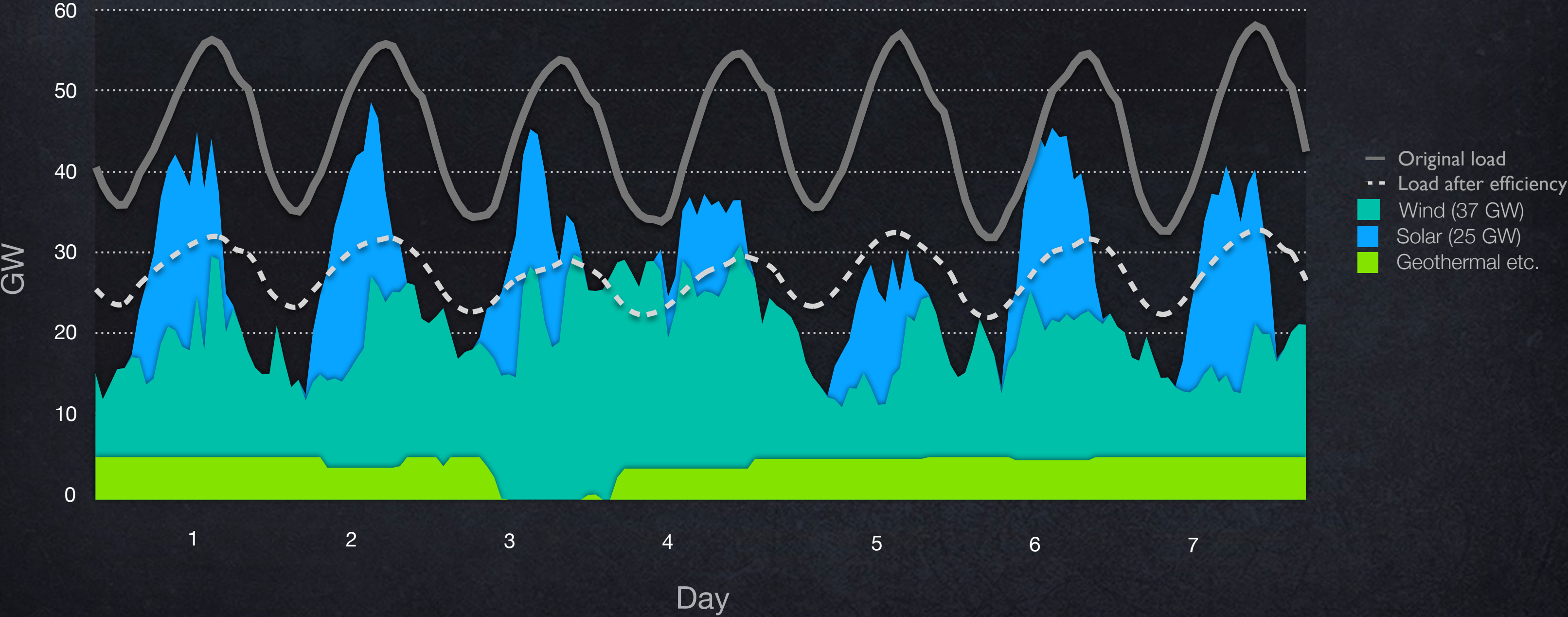
ERCOT power pool, Texas summer week, 2050 (RMI hourly simulation)





# Choreographing Variable Renewable Generation

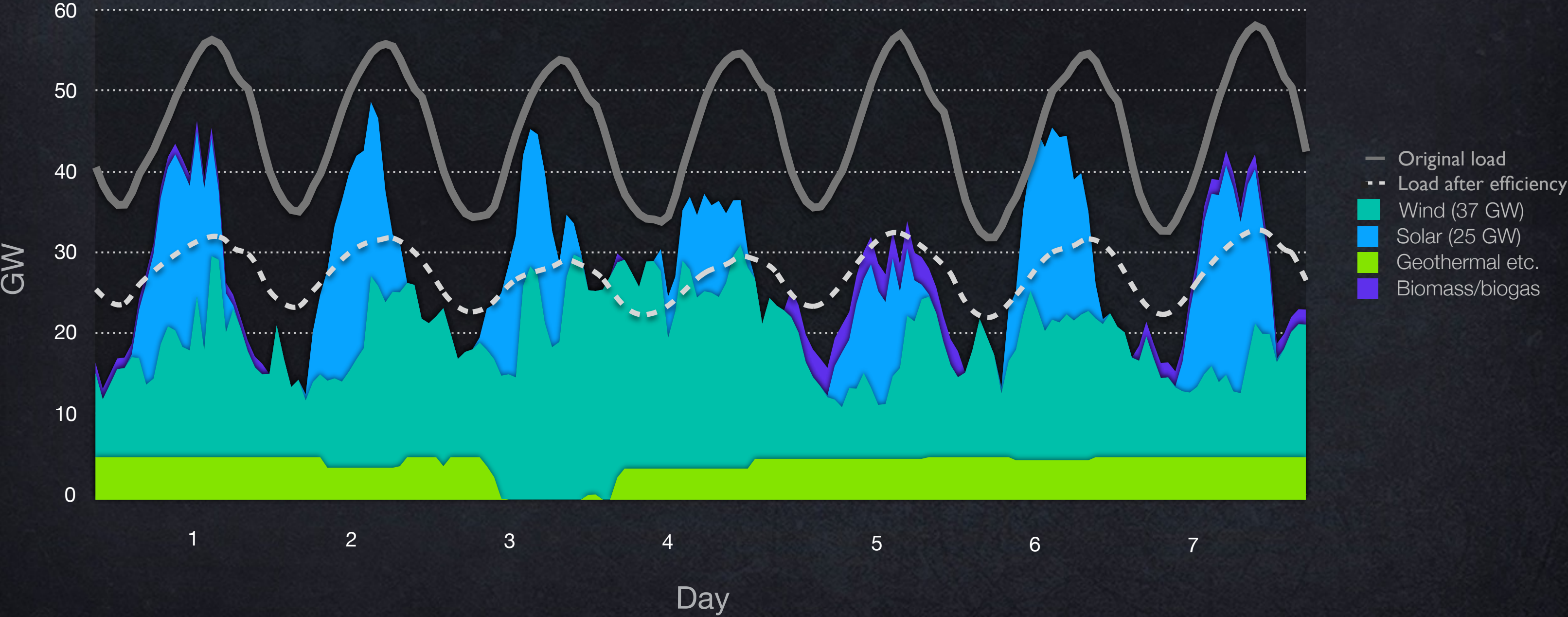
ERCOT power pool, Texas summer week, 2050 (RMI hourly simulation)





# Choreographing Variable Renewable Generation

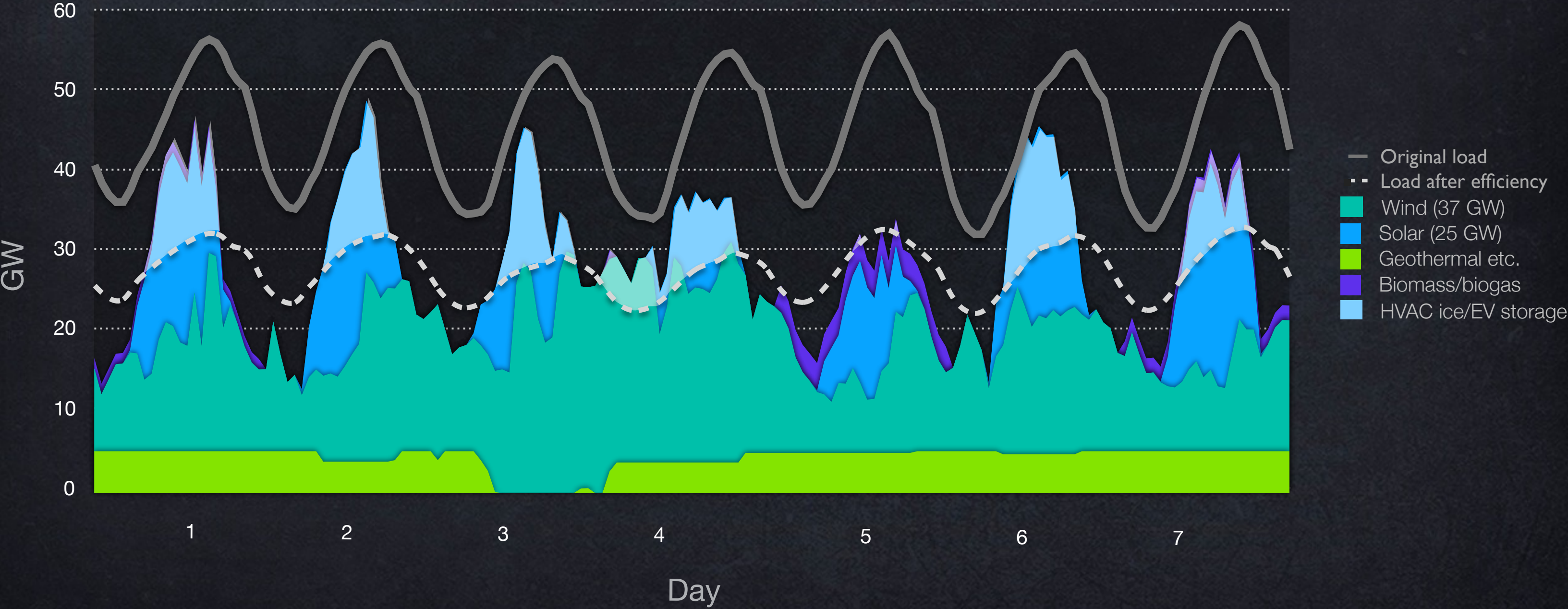
ERCOT power pool, Texas summer week, 2050 (RMI hourly simulation)





# Choreographing Variable Renewable Generation

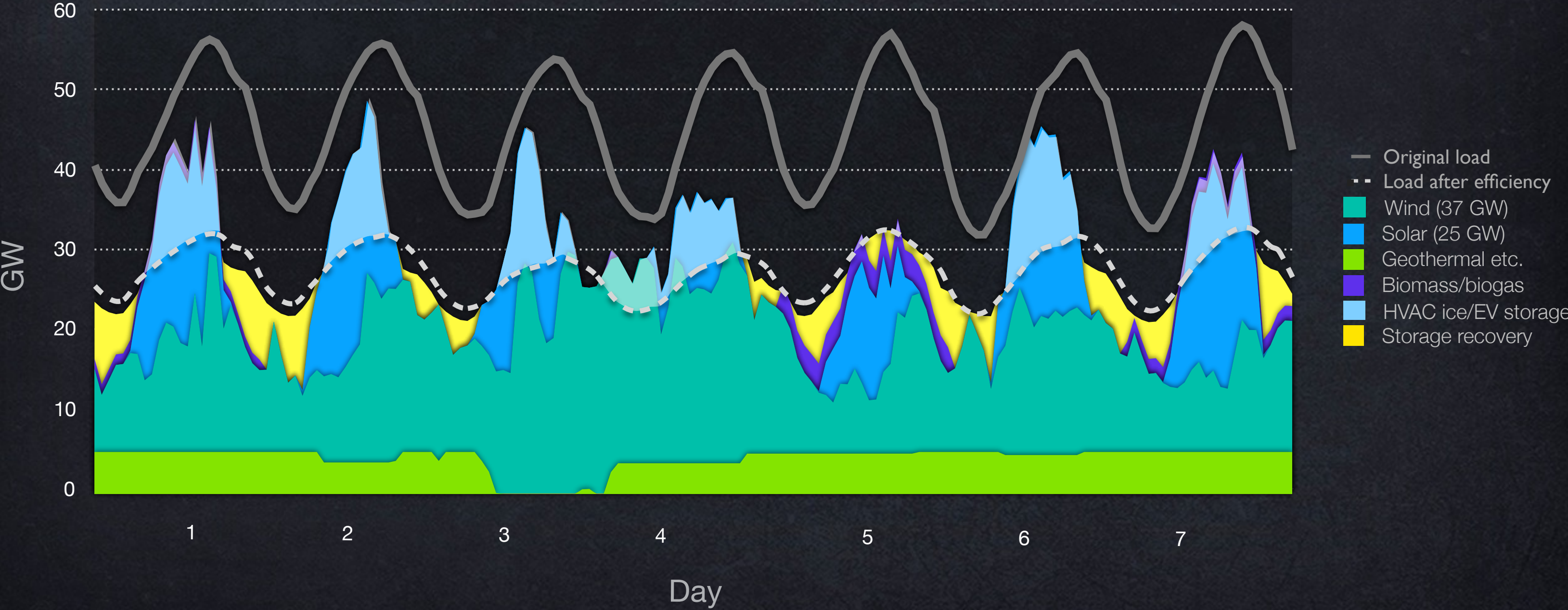
ERCOT power pool, Texas summer week, 2050 (RMI hourly simulation)





# Choreographing Variable Renewable Generation

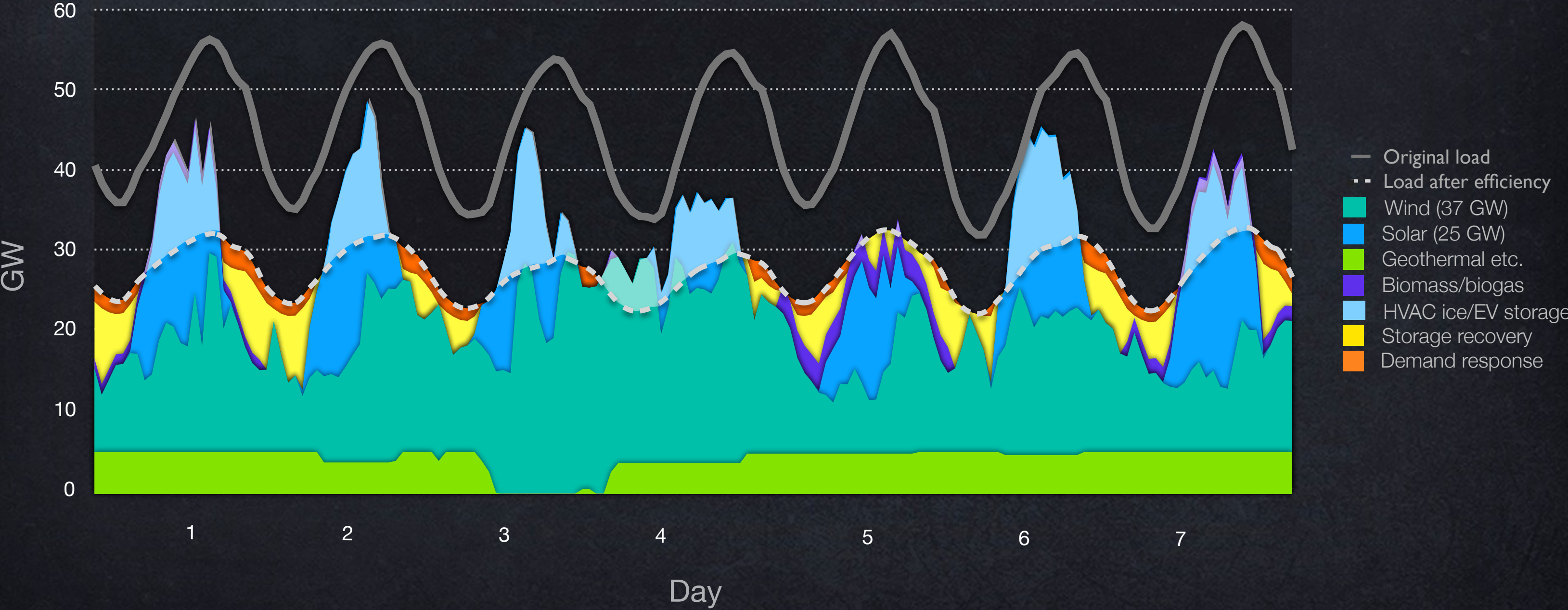
ERCOT power pool, Texas summer week, 2050 (RMI hourly simulation)





# Choreographing Variable Renewable Generation

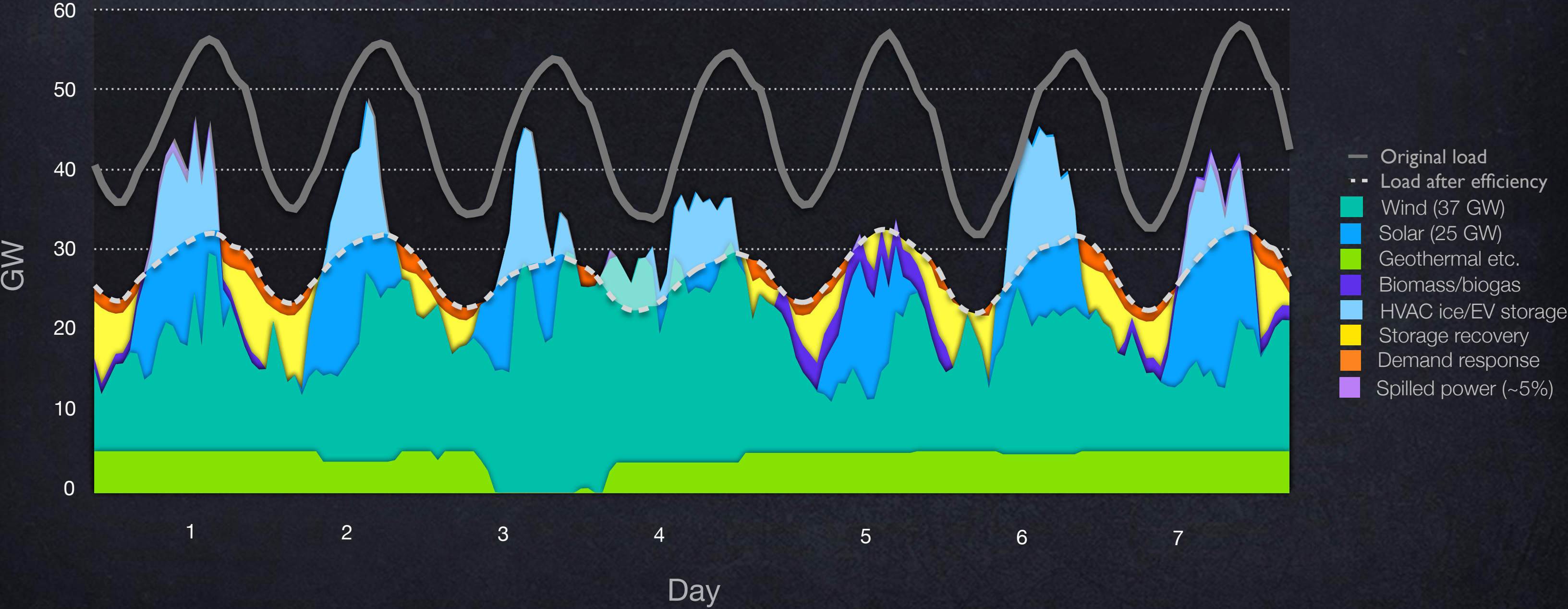
ERCOT power pool, Texas summer week, 2050 (RMI hourly simulation)





# Choreographing Variable Renewable Generation

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





# Choreographing Variable Renewable Generation

Europe, 2014 renewable %  
of total electricity consumed



# Choreographing Variable Renewable Generation

Europe, 2014 renewable %  
of total electricity consumed



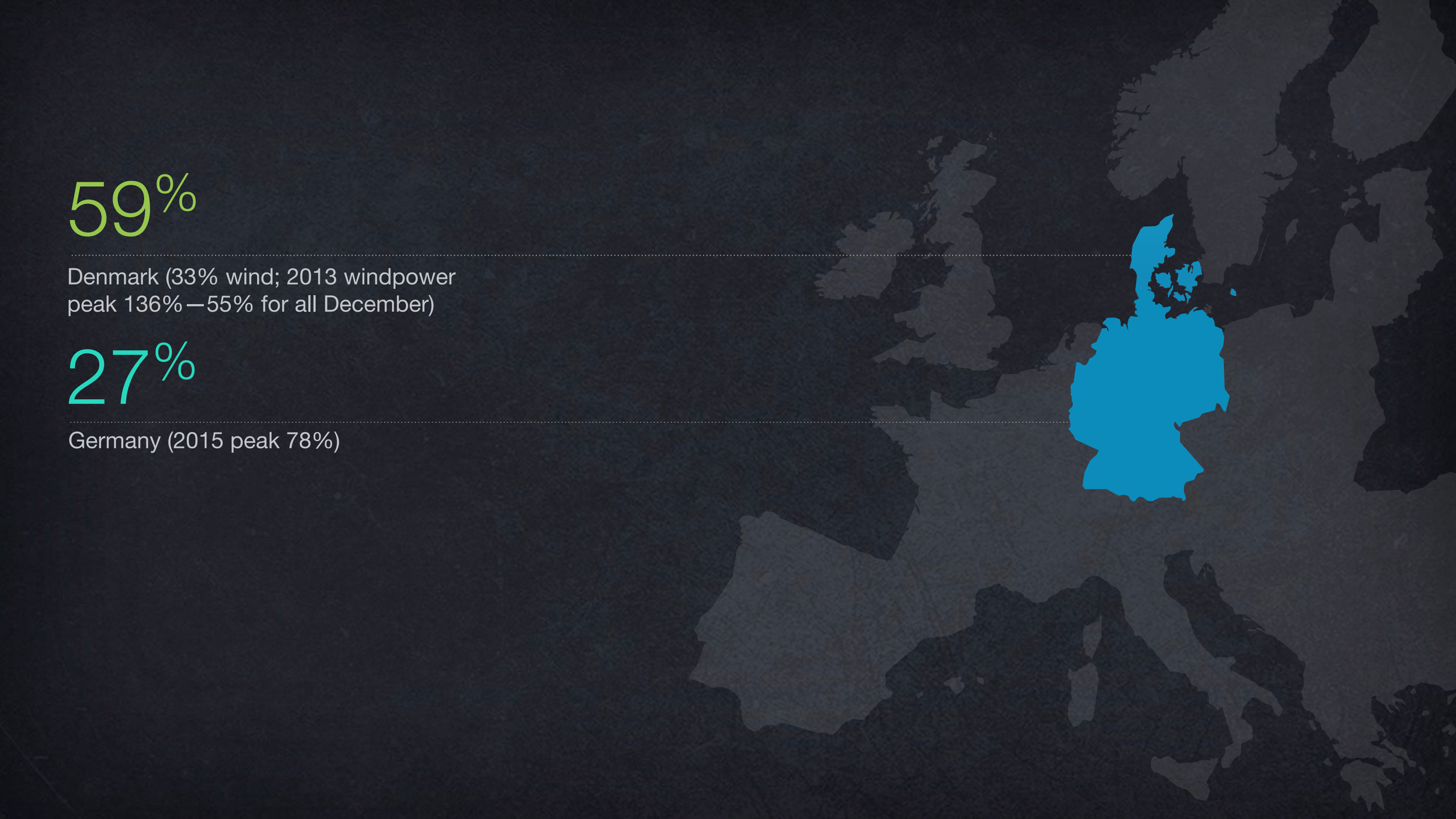


27%

Germany (2015 peak 78%)





A dark, textured map of Europe serves as the background. The country of Germany is highlighted in a solid red color, making it stand out from the rest of the map which is in shades of dark grey and black.

# 59%

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

# 27%

Germany (2015 peak 78%)



50%

Scotland

59%

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

27%

Germany (2015 peak 78%)





50%

Scotland

59%

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

27%

Germany (2015 peak 78%)

46%

Spain (including 21% wind, 14% hydro, 5% solar)





50%

Scotland

59%

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

27%

Germany (2015 peak 78%)

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)





# Choreographing Variable Renewable Generation

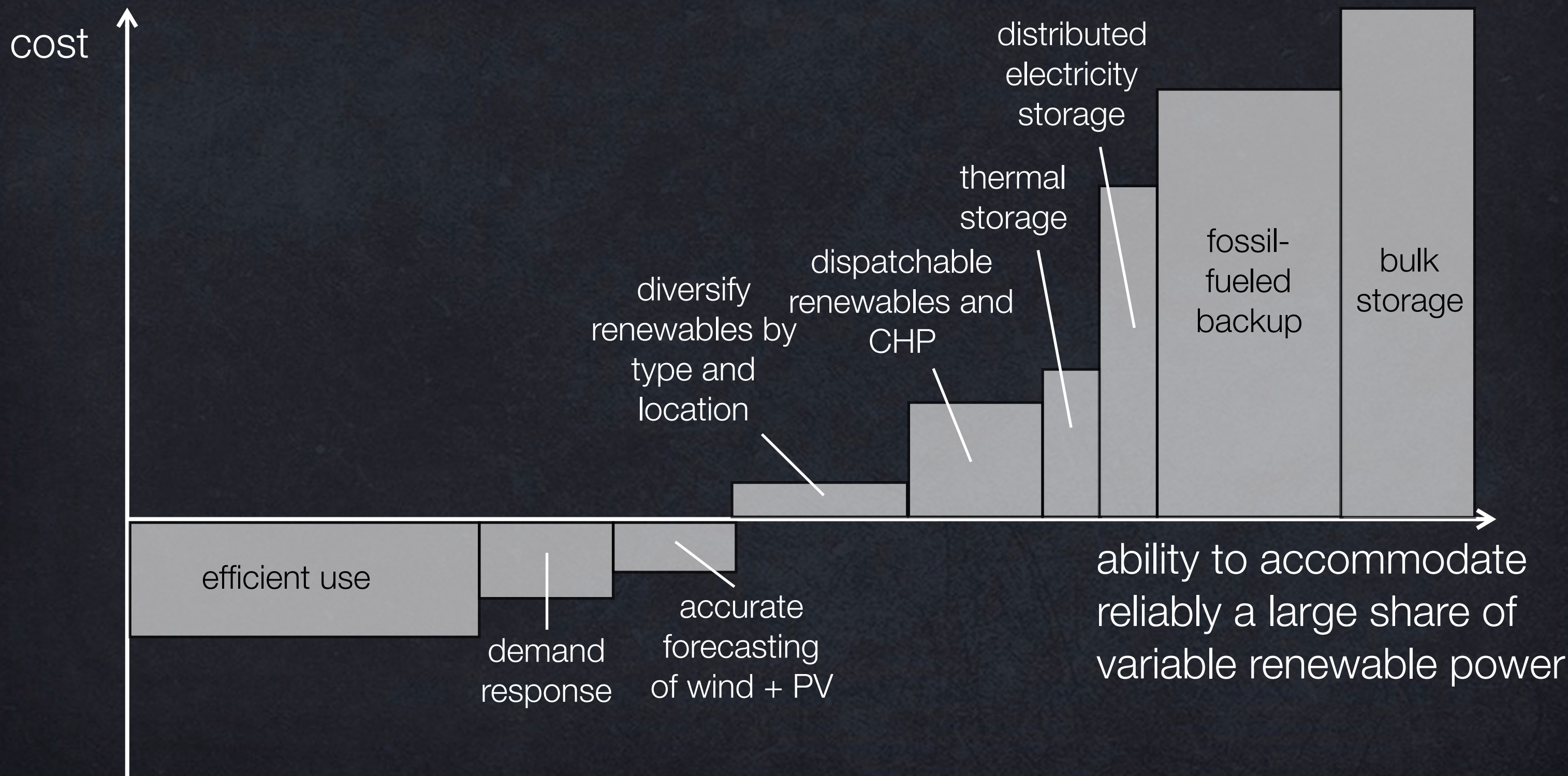
Europe, 2014 renewable %  
of total electricity consumed





# Grid flexibility supply curve

(all values shown are conceptual and illustrative)





# Denmark's transition to distributed electricity, 1980–2012

1980



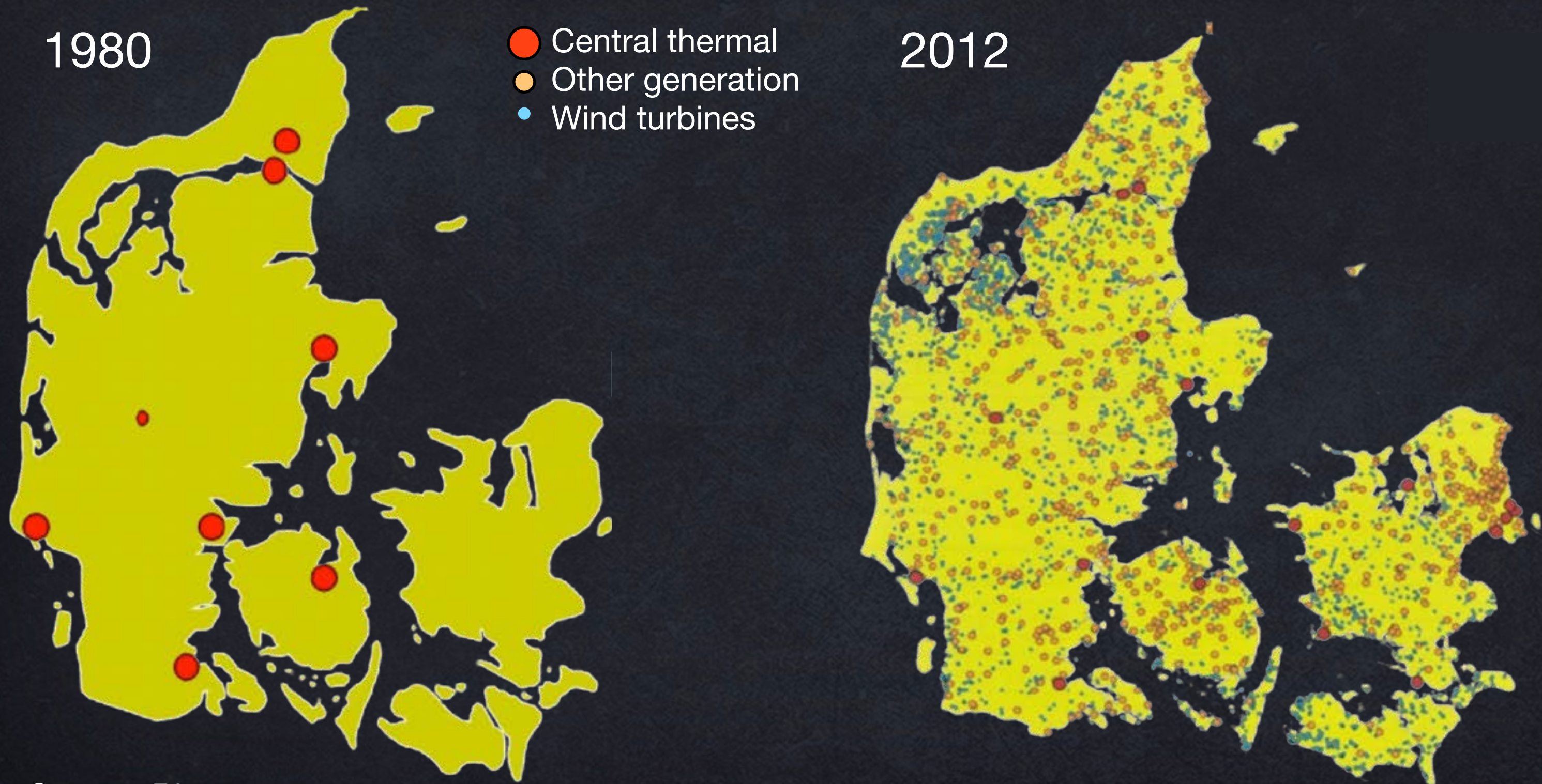
2012



Source: Risø



# Denmark's transition to distributed electricity, 1980–2012



Source: Risø







Similar

Costs



Similar

Costs

Different

Risks



# Cheaper renewables *and* batteries change the game

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

FIGURE ES3:

ECONOMICALLY OPTIMAL GENERATION MIX  
RESIDENTIAL

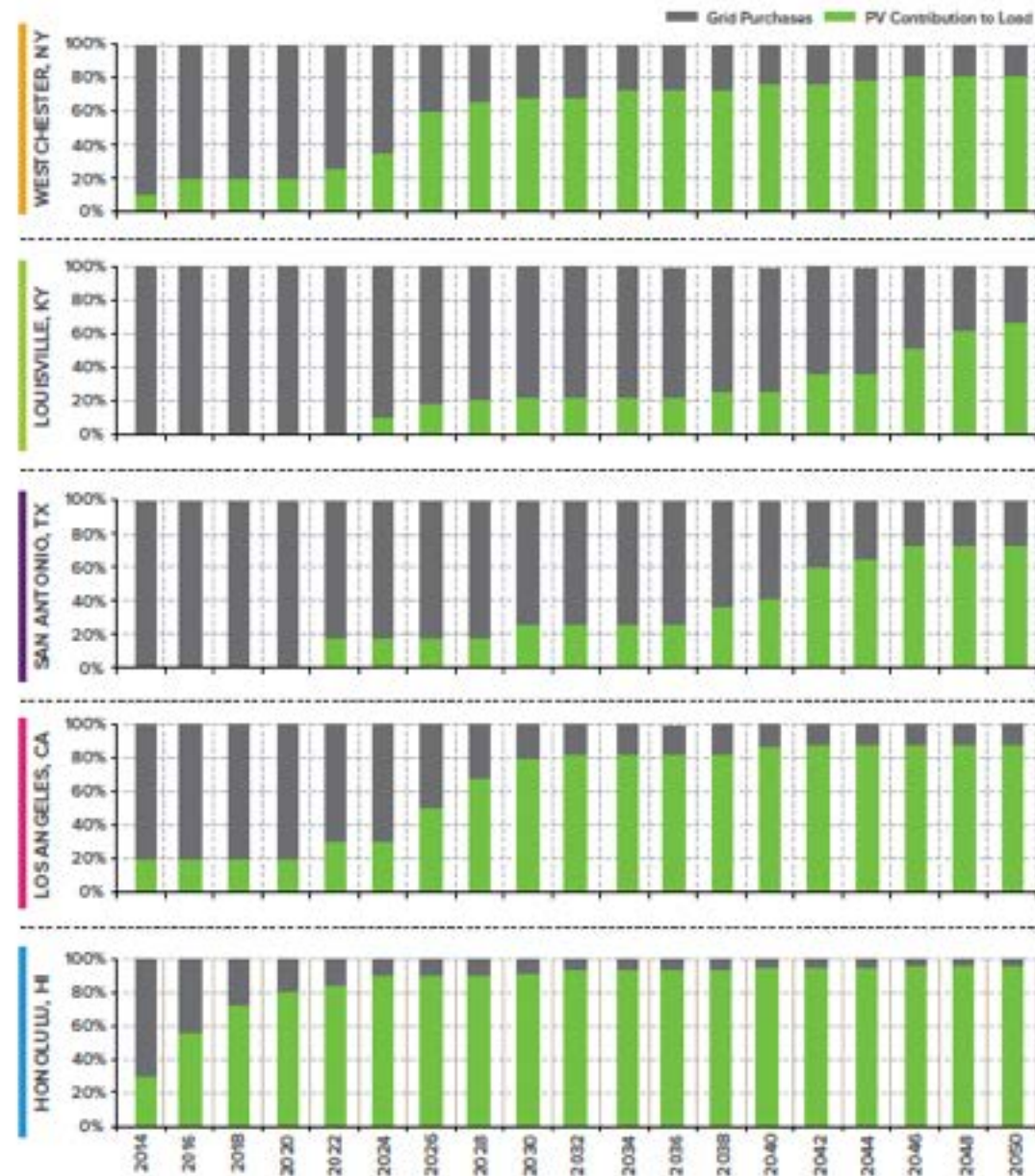
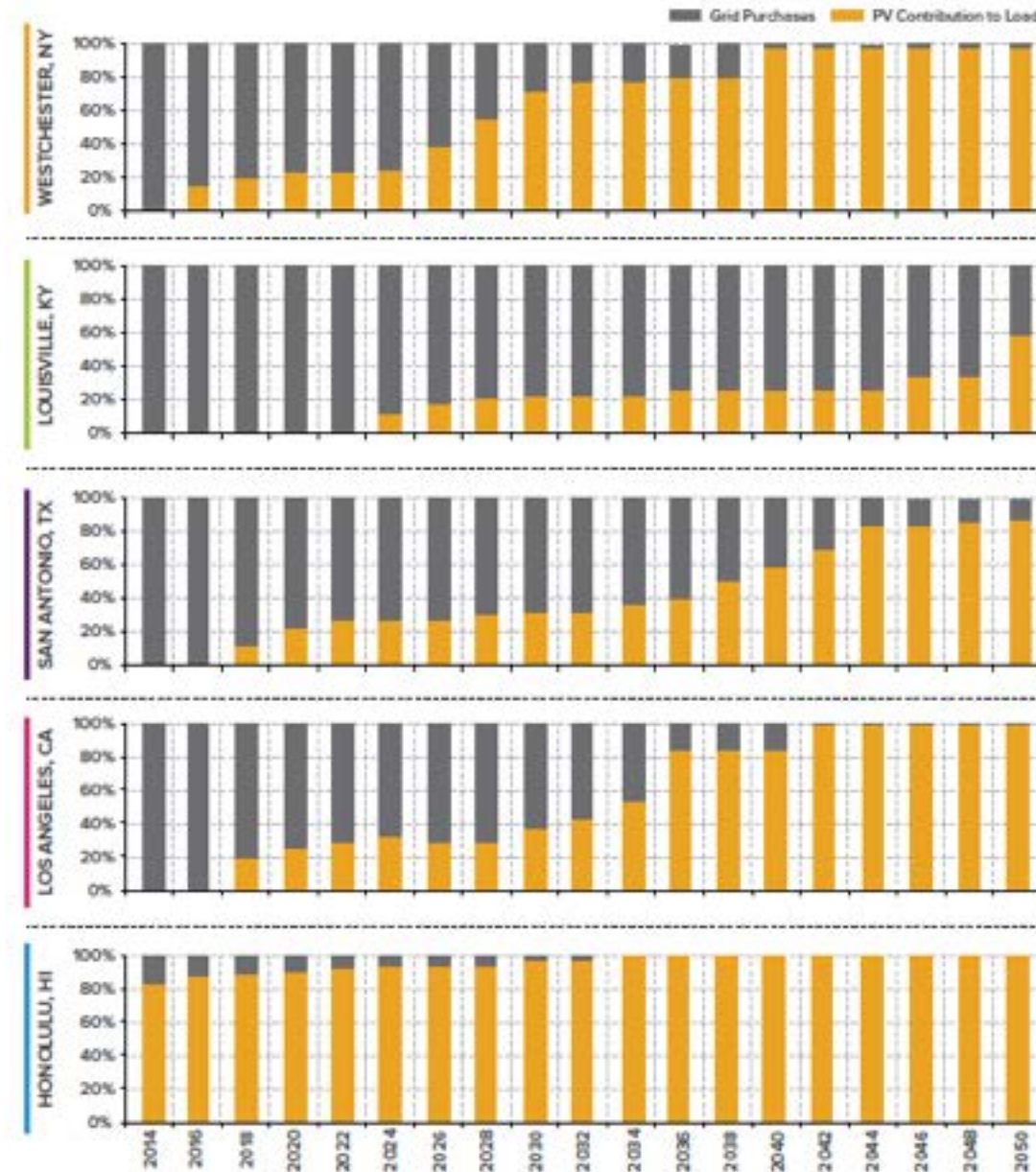


FIGURE ES4:

ECONOMICALLY OPTIMAL GENERATION MIX  
COMMERCIAL

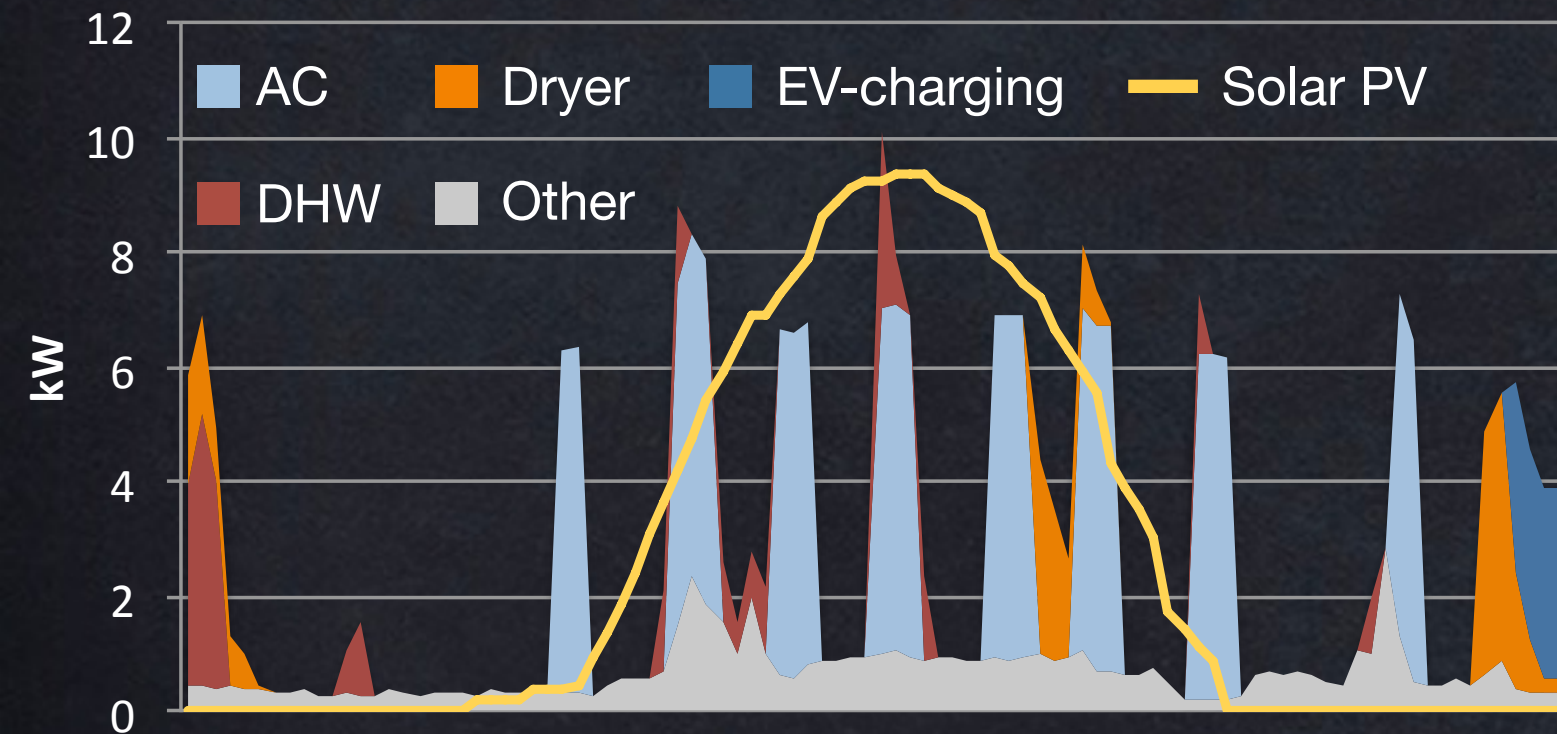




Load control + PVs = grid optional



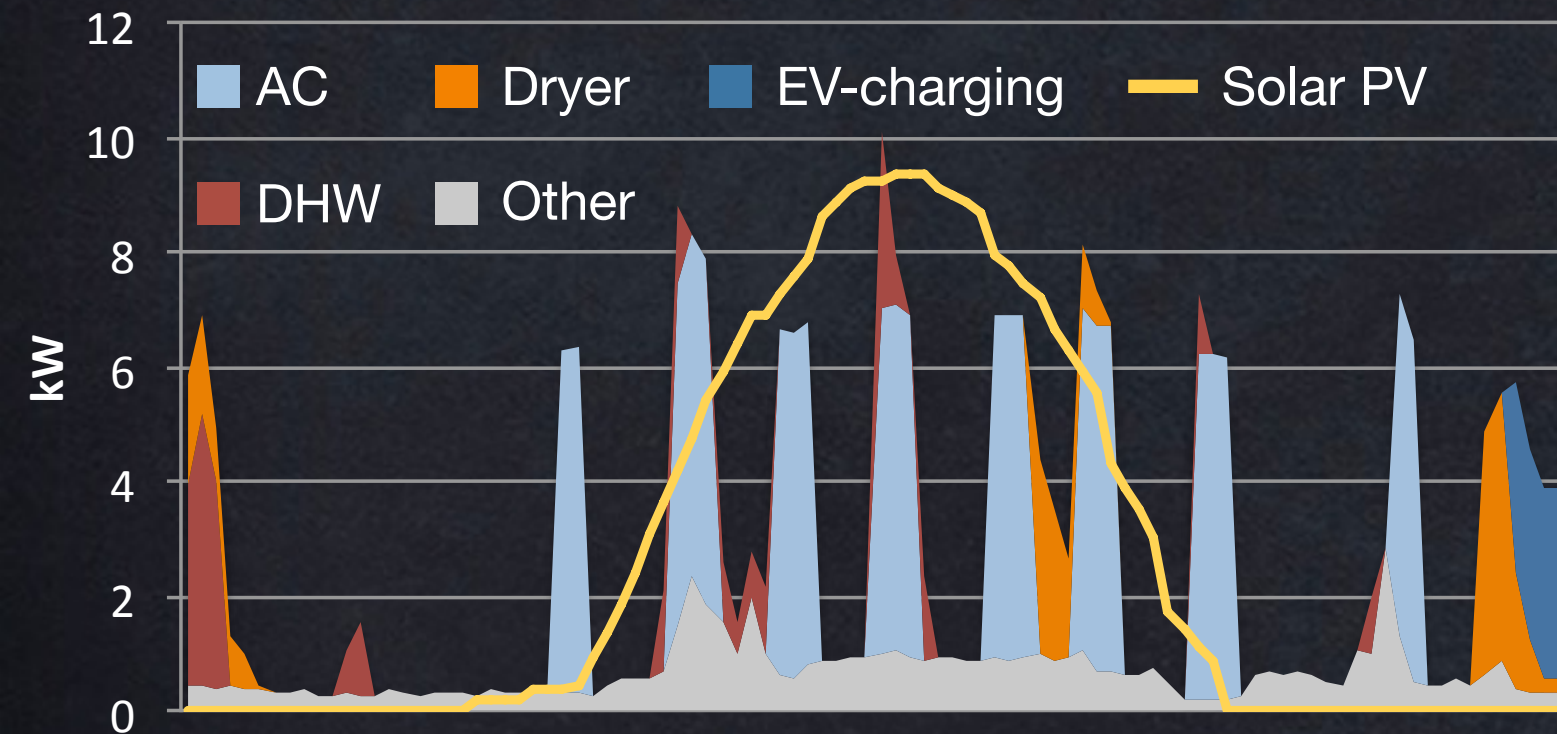
# Load control + PVs = grid optional



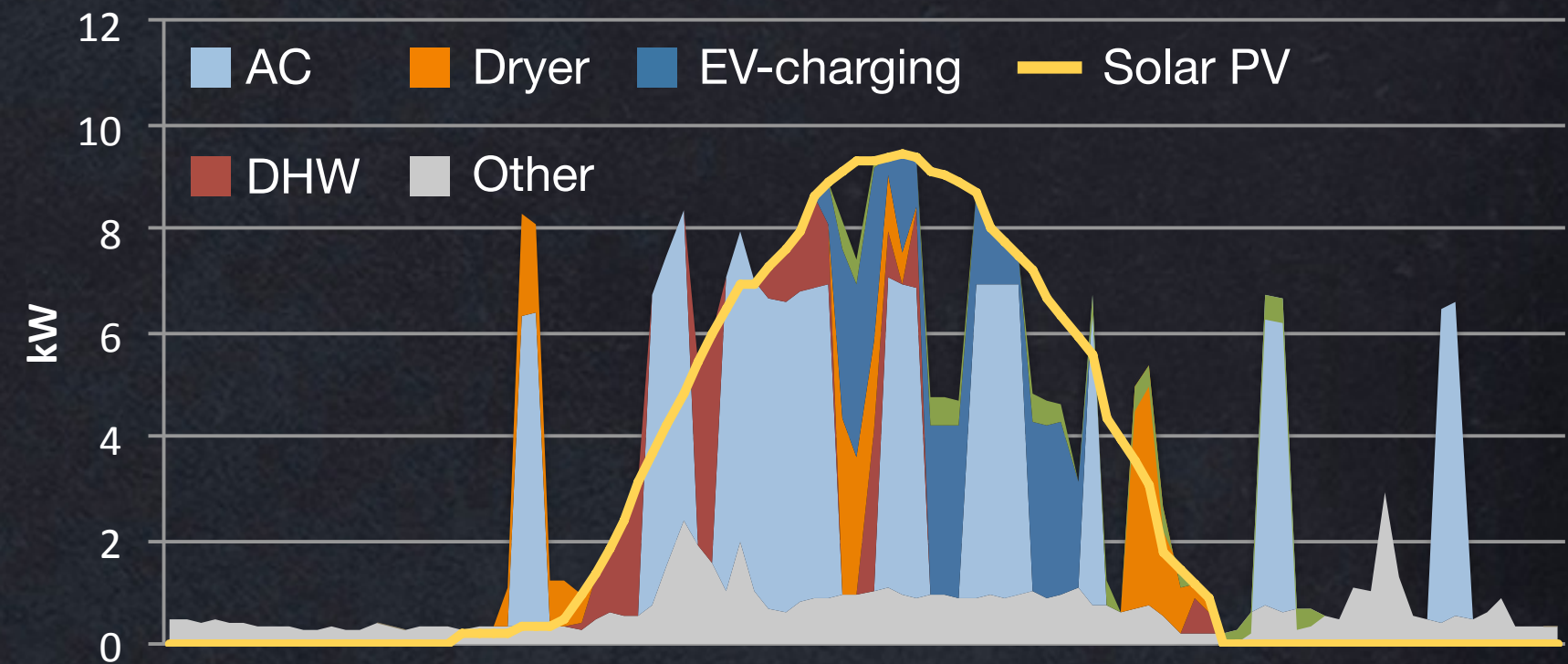
Uncontrolled: ~50% of solar PV production is sent to the grid, but if the utility doesn't pay for that energy, how could customers respond?



# 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.

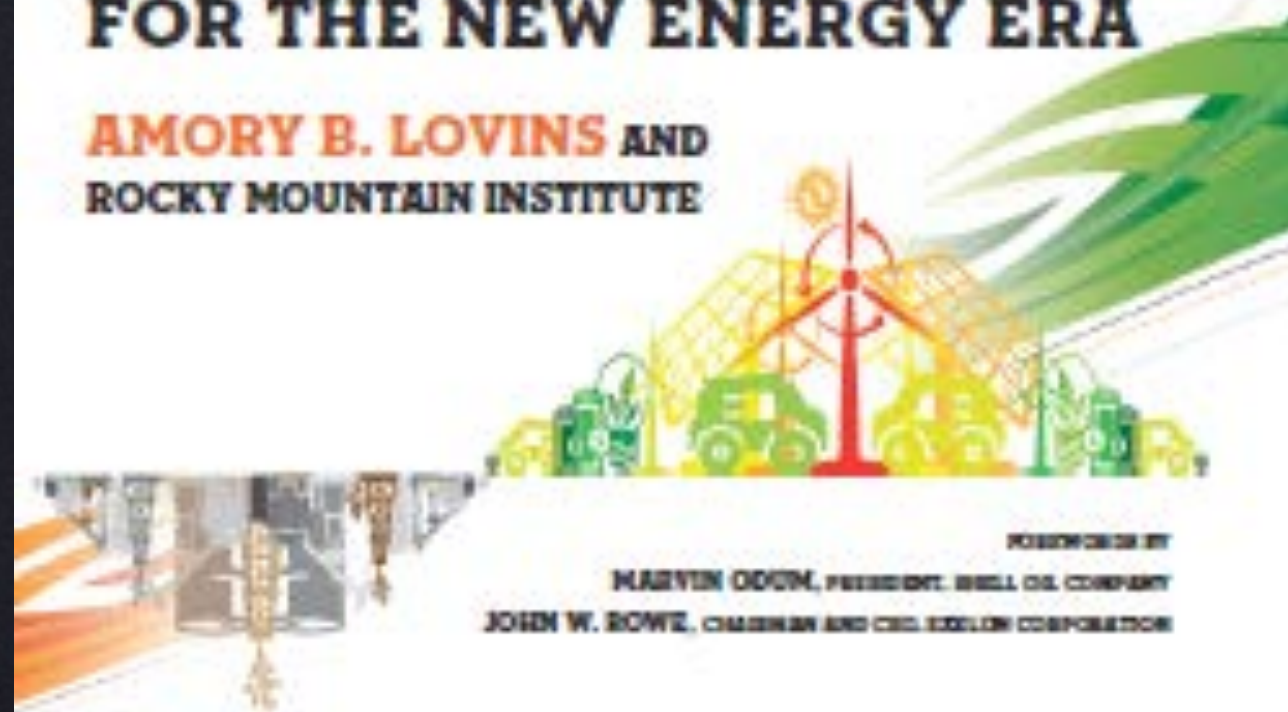


"A wise, detailed, and comprehensive blueprint" —President Bill Clinton

# REINVENTING FIRE®

**BOLD BUSINESS SOLUTIONS  
FOR THE NEW ENERGY ERA**

**AMORY B. LOVINS AND  
ROCKY MOUNTAIN INSTITUTE**



FOREWORD BY

MARVIN ODUM, PRESIDENT, SHELL OIL COMPANY

JOHN W. ROWE, CHAIRMAN AND CEO, EXXON CORPORATION

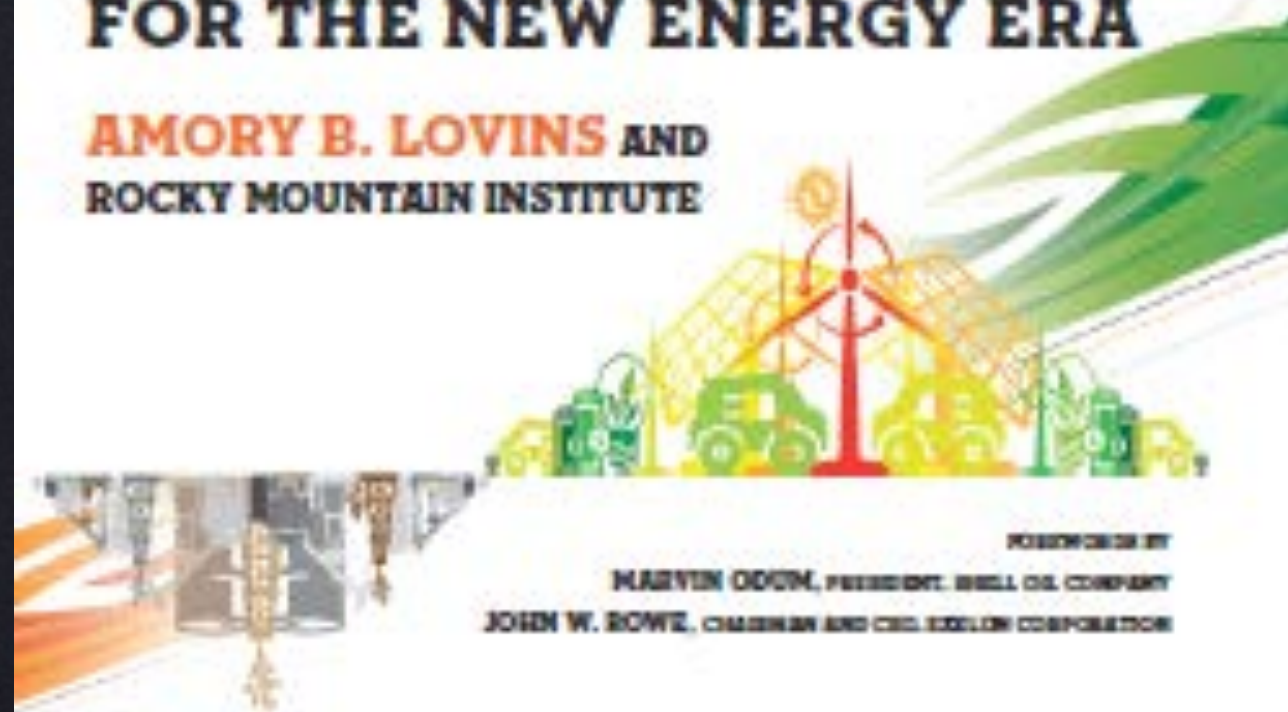


"A wise, detailed, and comprehensive blueprint" —President Bill Clinton

# REINVENTING FIRE

**BOLD BUSINESS SOLUTIONS  
FOR THE NEW ENERGY ERA**

**AMORY B. LOVINS AND  
ROCKY MOUNTAIN INSTITUTE**



FOREWORD BY  
MARVIN ODUM, PRESIDENT, SHELL OIL COMPANY  
JOHN W. ROWE, CHAIRMAN AND CEO, EXXON CORPORATION

REINVENTING  
**FIRE**



## 重塑能源

新能源世纪的商业解决方案

**BOLD BUSINESS SOLUTIONS FOR THE NEW ENERGY ERA**

阿莫·洛文斯、洛文斯山研究所 著  
陈伟明、陈伟明设计中心 译  
中信出版社 出版











\$5T

in savings

+158%

bigger economy

0

oil, coal, nuclear







Solutions to:



Solutions to:





Solutions to:





Solutions to:





Solutions to:

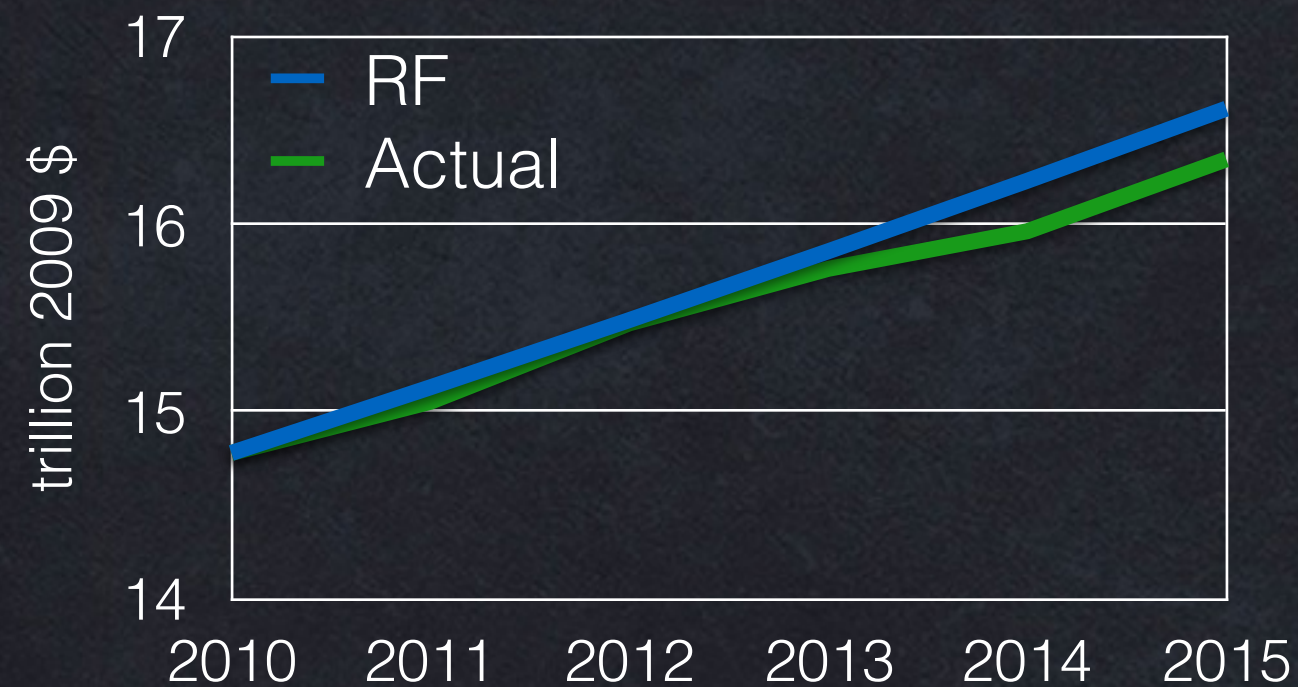




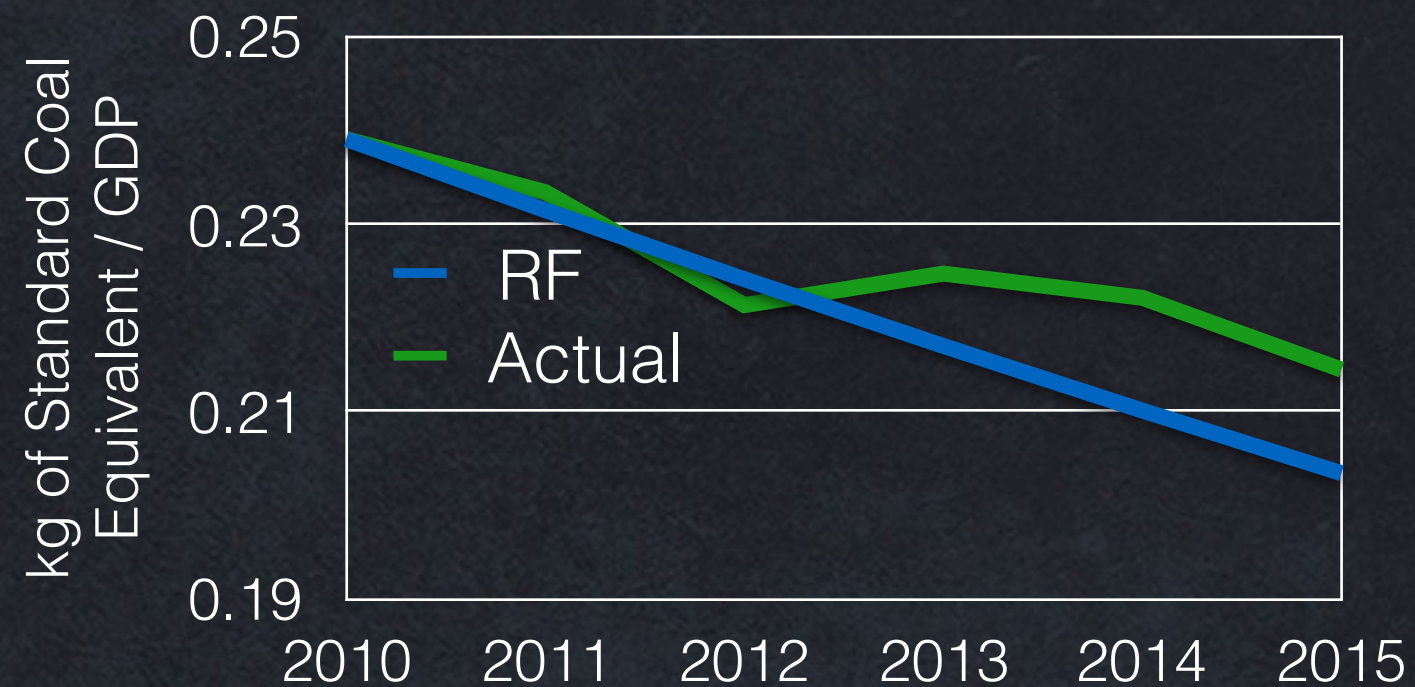
# 2010–2015<sub>p</sub> U.S. progress toward *Reinventing Fire's* 2050 goals

Actuals (USEIA) are not weather-adjusted; 2015 data through Nov. *Reinventing Fire* progression based on constant exponential growth rate.

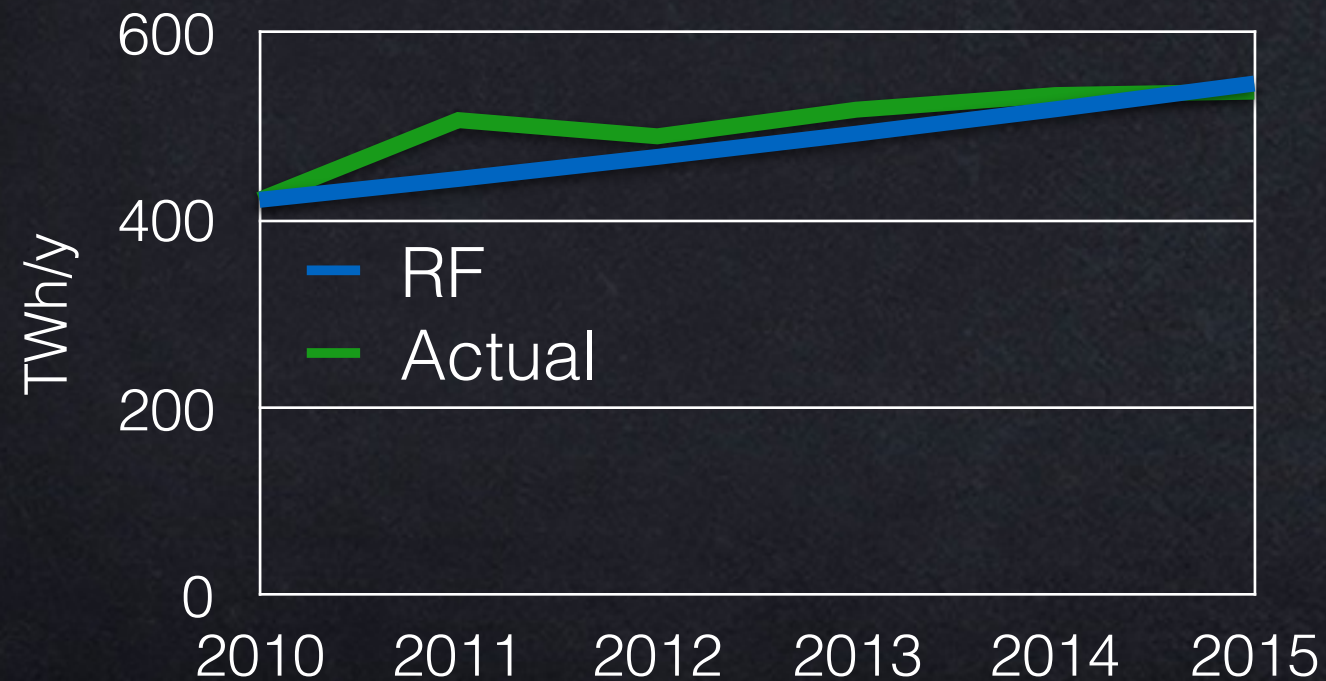
## GDP



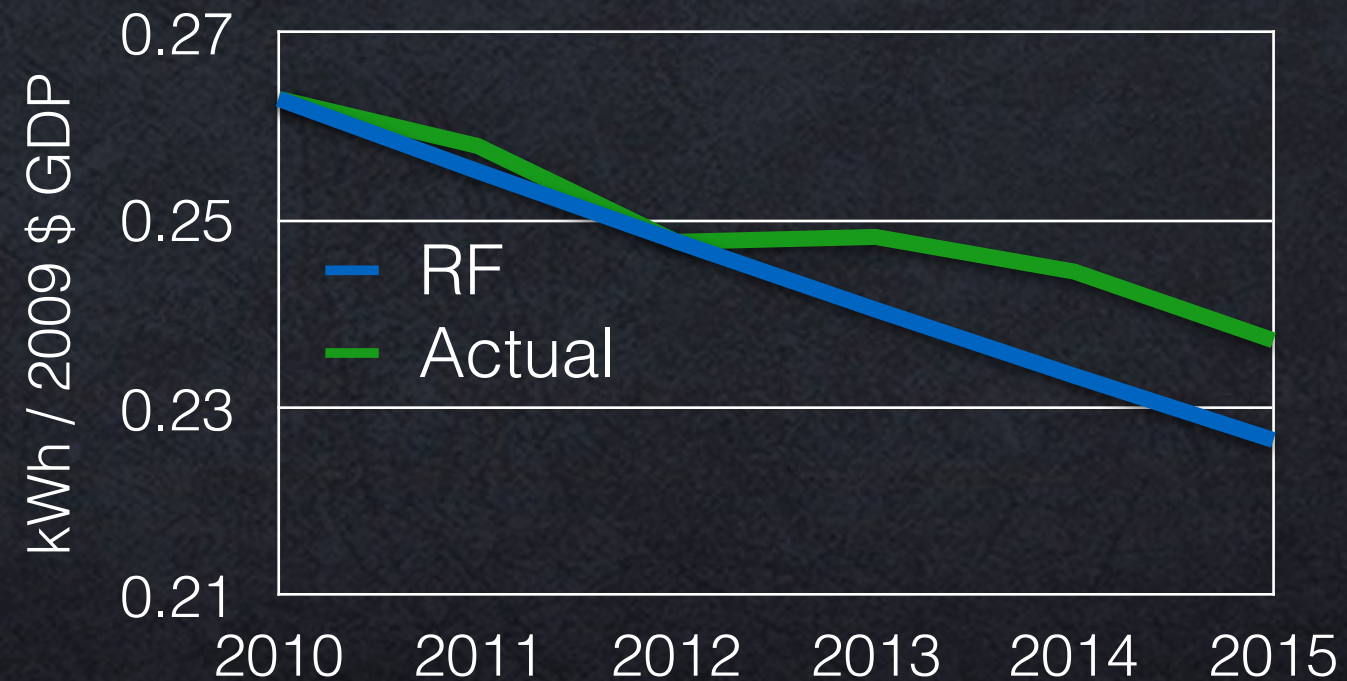
## Primary Energy Intensity



## Renewable Electricity Generation



## Electric Intensity





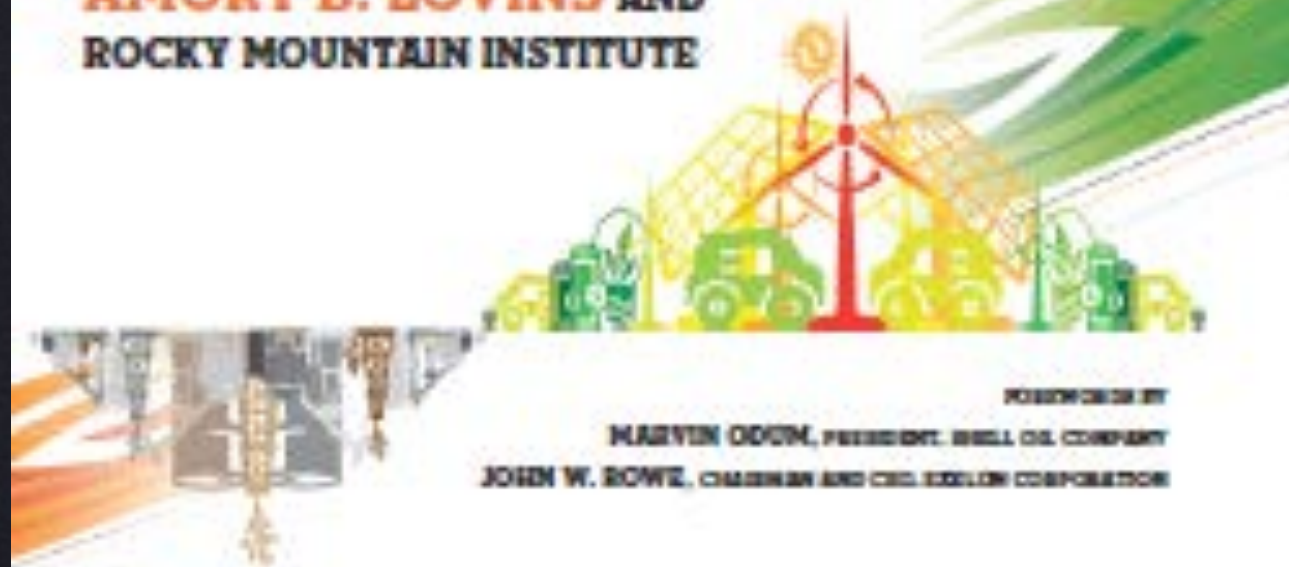
"A wise, detailed, and comprehensive blueprint" —President Bill Clinton

# REINVENTING FIRE

**BOLD BUSINESS SOLUTIONS  
FOR THE NEW ENERGY ERA**

**AMORY B. LOVINS AND  
ROCKY MOUNTAIN INSTITUTE**

FOREWORD BY  
MARTIN ODUM, PRESIDENT, SHEL OIL COMPANY  
JOHN W. ROWE, CHAIRMAN AND CEO, EXXON CORPORATION



## REINVENTING FIRE: CHINA

A ROADMAP FOR CHINA'S REVOLUTION  
IN ENERGY CONSUMPTION AND  
PRODUCTION TO 2050

## 重塑能源：中国

面向2050年能源消费和生产革命路线图研究

### EXECUTIVE SUMMARY

AUGUST 2016

ENERGY RESEARCH INSTITUTE OF THE NATIONAL DEVELOPMENT AND REFORM COMMISSION,  
THE CHINA ENERGY GROUP OF LAWRENCE BERKELEY NATIONAL LABORATORY, AND  
ROCKY MOUNTAIN INSTITUTE

SUPPORTING PARTNER: ENERGY FOUNDATION CHINA







2010 NPV





RMB 21T  
2010 NPV

in savings  
经济节约

+587%

bigger GDP  
经济规模

38%

less carbon  
碳排放减少



Couldn't India aspire to do that well or better?









Price > Cost



Value > Price > Cost



# Easter Parades on Fifth Avenue, New York, 13 years apart

1900: where's the first car?





# Easter Parades on Fifth Avenue, New York, 13 years apart

1900: where's the first car?





# Easter Parades on Fifth Avenue, New York, 13 years apart

1900: where's the first car?



1913: where's the last horse?



Images: L, National Archive, [www.archives.gov/research/american-cities/images/american-cities-101.jpg](http://www.archives.gov/research/american-cities/images/american-cities-101.jpg); R, [shorpy.com/node/204](http://shorpy.com/node/204).

Inspiration: Tona Seba's keynote lecture at AltCar, Santa Monica CA, 28 Oct 2014, <http://tonyseba.com/keynote-at-altcar-expo-100-electric-transportation-100-solar-by-2030/>



# Easter Parades on Fifth Avenue, New York, 13 years apart

1900: where's the first car?



1913: where's the last horse?



Images: L, National Archive, [www.archives.gov/research/american-cities/images/american-cities-101.jpg](http://www.archives.gov/research/american-cities/images/american-cities-101.jpg); R, [shorpy.com/node/204](http://shorpy.com/node/204).

Inspiration: Tona Seba's keynote lecture at AltCar, Santa Monica CA, 28 Oct 2014, <http://tonyseba.com/keynote-at-altcar-expo-100-electric-transportation-100-solar-by-2030/>



# A new and old utility



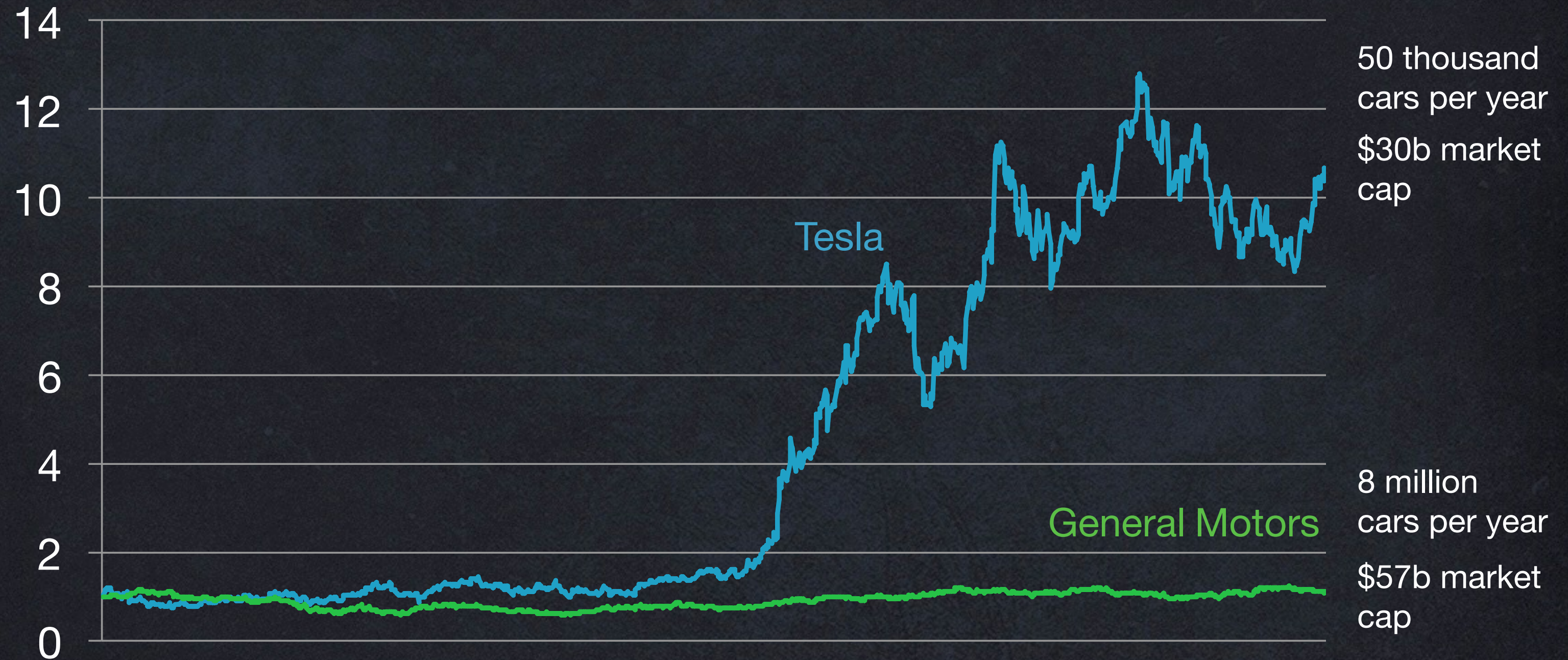


# A new and old utility



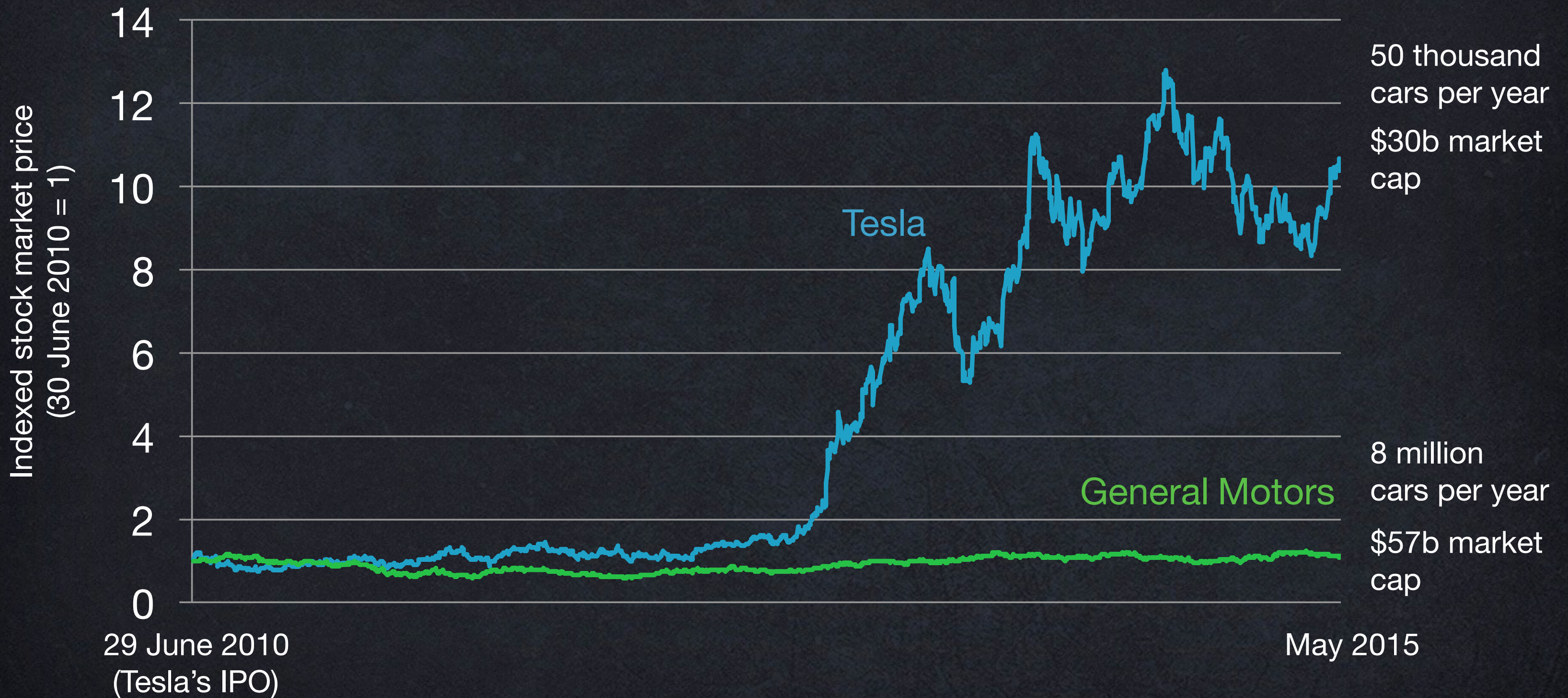


# A new and old automaker





# A new and old automaker





# From the Age of Carbon to the Age of Silicon





# From the Age of Carbon to the Age of Silicon





Renewables replacing \$38b/y kerosene market





# Renewables replacing \$38b/y kerosene market







[reinventingfire.com](http://reinventingfire.com) | [www.rmi.org](http://www.rmi.org), [ablovins@rmi.org](mailto:ablovins@rmi.org) | Twitter @AmoryLovins

[www.ted.com/talks/amory\\_lovins\\_a\\_50\\_year\\_plan\\_for\\_energy.html](http://www.ted.com/talks/amory_lovins_a_50_year_plan_for_energy.html)

[www.rmi.org/Knowledge-Center/Library/2012-01\\_FarewellToFossilFuels](http://www.rmi.org/Knowledge-Center/Library/2012-01_FarewellToFossilFuels)