ADVANCED ENERGY ECONOMY

ADVANCED ENERGY NOW

2019 Market Report

Global and U.S. Markets by Revenue 2011-18 and Key Trends in Advanced Energy Growth

Sponsored by

Prepared by Navigant Research

Advanced Energy Now 2019 Market Report

ADVANCED ENERGY ECONOMY

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ABOUT ADVANCED ENERGY ECONOMY

Advanced Energy Economy (AEE) is a national association of businesses that are making the energy we use secure, clean, and affordable. Advanced energy encompasses a broad range of products and services that constitute the best available technologies for meeting energy needs today and tomorrow. AEE's mission is to transform public policy to enable rapid growth of advanced energy businesses. Engaged at the federal level and in more than a dozen states around the country, AEE represents more than 100 companies in the $238 billion U.S. advanced energy industry, which employs 3.5 million U.S. workers. Learn more at www.aee.net and follow the latest industry news @AEEnet.

ABOUT NAVIGANT RESEARCH

Navigant Research, a part of Navigant Consulting's Energy Practice, is a market research and advisory group that provides in-depth analysis of global clean technology markets with a specific focus on the commercialization and market growth opportunities for emerging energy technologies. Our client base includes Fortune 1000 multinational technology and energy companies, government agencies, utilities, investors, industry associations, and clean technology pure plays. We provide these companies with market research reports, custom research engagements, and subscription-based research services. Navigant is focused across four research programs: Energy Technologies, Utility Transformations, Transportation Efficiencies, and Building Innovations.

Additional information about Navigant Research can be found at www.navigantresearch.com.

FOREWORD

Welcome to the latest edition of Advanced Energy Now Market Report, prepared for Advanced Energy Economy by Navigant Research. First, let me thank our sponsor, Apex Clean Energy, for helping to make this year's market report possible.

The 2019 edition is full of good news about industry growth. But at AEE, our mission isn't just to report on the growth of advanced energy – it is to keep it going. Advanced energy has strong momentum in the marketplace, but it is an industry where public policy, both state and federal, can provide a tailwind or a headwind. AEE keeps the public policy wind in our industry's sails.

AEE represents the full range of technologies and services that make the energy we use secure, clean, and affordable; the companies that provide them; and the companies that buy them. Taking a systems approach, we concentrate on policy opportunities that expand markets and the amount of margin within them for the widest range of businesses constituting the advanced energy industry.

We do that by rigorously aligning the portfolio of policy changes we are seeking with opportunities to expand markets for advanced energy products and services and the value of these markets to our member companies. And then we put behind these campaigns the resources needed to win.

That takes AEE to multiple states around the country, because energy policy is primarily set at the state level. That is where the breakthroughs in legislation and regulation that create bigger, and ultimately national, markets take place.

It also takes AEE to the organized wholesale markets governed by the Federal Energy Regulatory Commission. Market rules can enable, or thwart, new technologies and services as they strive to compete fairly, on the basis of price and performance. AEE is there to make sure they get the chance.

We also help you – businesses and advocates for advanced energy, inside government and out – help yourself. Our **PowerSuite** technology platform allows users to manage energy policy risks and opportunities across the country with one, easy-to-use interface.

If your company is in the advanced energy industry, you should be involved with AEE – as a member, or as a subscriber to **PowerSuite**. If you're not already, please get in touch with us, at AEE.net.

Nat Kreamer

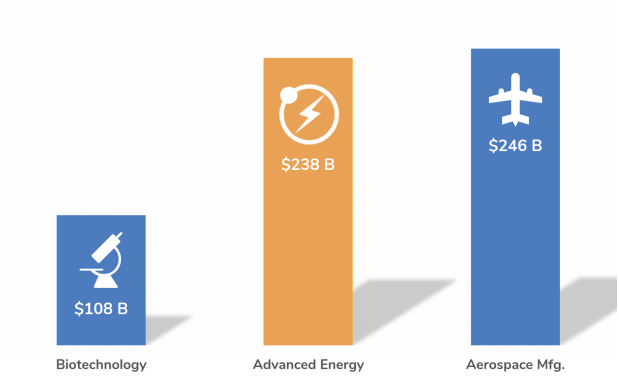
CEO, Advanced Energy Economy

ADVANCED ENERGY CONTINUES TO GROW

Advanced energy is a $1.6 trillion global industry, equal in revenue to the tourism industry, bigger than pharmaceuticals, and almost twice the size of the global airline industry.

The U.S. advanced energy industry generated $238 billion in revenue in 2018, roughly equal to aerospace manufacturing and double the biotechnology industry.

U.S. Revenue by Industry



Revenue in 2018 was up 11% – nearly four times the rate of the U.S. economy overall. Since 2011, when AEE began tracking, U.S. advanced energy revenue has grown at a compound annual rate of 6%.

The bulk of the $25 billion U.S. revenue growth overall came in three segments: **Advanced Transportation** (up $7.9 billion), **Building Efficiency** (up $7.8 billion), and **Advanced Fuel Production** (up $5.4 billion).

WHAT IS ADVANCED ENERGY?

$1.6 TRILLION

global industry revenue

$238 BILLION

U.S. industry revenue

3.5 MILLION

U.S. advanced energy jobs

As defined by national business association Advanced Energy Economy (AEE), advanced energy is a broad range of technologies, products, and services that constitute the best available technologies for meeting energy needs today and tomorrow. Prepared by Navigant Research, *Advanced Energy Now 2019 Market Report* is the sixth report of market size, by revenue, of the advanced energy industry worldwide and in the United States. The industry consists of seven segments:

- **BUILDING EFFICIENCY**
- **ELECTRICITY DELIVERY & MANAGEMENT**
- **ADVANCED TRANSPORTATION**
- **ADVANCED FUEL PRODUCTION**
- **ADVANCED INDUSTRY**
- **ADVANCED FUEL DELIVERY**
- **ADVANCED ELECTRICITY GENERATION**

NOTABLE U.S. GROWTH IN 2018

REVENUE GROWTH

$7.9 BILLION

in advanced transportation

$7.8 BILLION

in building efficiency

PERCENTAGE GROWTH

75%

in electric vehicles

23%

in charging infrastructure

23%

in wind energy

18%

in energy storage

Advanced Transportation saw both the largest increase and the fastest growth in 2018 (34%). Leading this growth was revenue from Plug-in Electric Vehicles (PEVs), up 75% from 2017, to $18 billion. PEV growth has been explosive, with a compound annual growth rate (CAGR) of 59% since 2011.

Building Efficiency – the largest segment of U.S. advanced energy revenue – saw 10% revenue growth in 2018, continuing its streak of year-over-year increases. Counting only products for which we have eight years of data, Building Efficiency has grown at a CAGR of 11% since 2011.

Advanced Fuel Production staged a comeback in 2018, growing 18%, to $33.4 billion. With sharp declines in 2015 and 2016, Ethanol revenue rebounded, up 20% in 2018 to $22.4 billion. Biodiesel fuels had their biggest year yet – up 43%, to $6.6 billion.

Advanced Electricity Generation revenue also grew in 2018, up 8% to $59.6 billion. **Revenue from Wind energy was up 23%, to $14 billion, after a dip of 19% in 2017. Solar PV was up 8% over 2017, at $24.2 billion.** Continued falling costs allowed for an increase in installed capacity of 14%. Solar PV revenue has grown at CAGR of 17% since 2011.

Within Advanced Electricity Delivery and Management, **Energy Storage was up 18%, to $701 million, after a bigger year in 2017 (39%), while Electric Vehicle Charging Infrastructure was up 23%, to $280 million.** Revenue from Smart Meters jumped 81% in 2017 before declining 6% last year. **At $1.1 billion in 2018, Smart Meter revenue was still close to its peak of $1.4 billion in 2011 and 2012.**

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INTRODUCTION

The *Advanced Energy Now 2019 Market Report* is the sixth report of market size, by revenue, of the advanced energy industry, worldwide and in the United States.

As defined by Advanced Energy Economy (AEE) – a national association of businesses making the energy we use secure, clean, and affordable – advanced energy is a broad range of technologies, products, and services that constitute the best available technologies for meeting energy needs today and tomorrow. Defined in this way, advanced energy is not static but dynamic, as innovation and competition produce better energy technologies, products, and services over time. Today, electric and plug-in hybrid cars, natural gas-fueled trucks, high-performance buildings, energy-saving industrial processes, wind turbines, onsite and utility-scale solar power, and nuclear power plants are all examples of advanced energy, as they diversify energy sources, reduce health and environmental costs to communities, and use energy resources more productively.

Advanced energy represents an opportunity for U.S. companies and workers not only to serve the domestic market but to export goods and services into the global energy markets.

Advanced energy consists of seven broad industry segments and 41 subsegments, each of which contains multiple product categories, enumerated in the figure to the right.

ENERGY SUPPLY

Advanced Electricity Generation

- Hydropower
- Gas turbines
- Solar
- Wind
- Geothermal
- Marine
- Waste
- Biomass
- Nuclear
- Other DG

Electricity Delivery & Management

- Transmission
- Distribution
- AMI
- Microgrids
- EV Charging Infrastructure
- Energy Storage
- Enabling IT

Advanced Fuel Production

- Ethanol & Butanol
- Biodiesel
- Bio-methane
- Synthetic Diesel & Gasoline
- Bio-oil
- CNG & LNG
- Hydrogen

Advanced Fuel Delivery

- Fuel Transportation Infrastructure
- Fueling Stations

ENERGY DEMAND

Building Efficiency

- Building Design
- Building Envelope
- HVAC
- District Energy, CHP, CCHP
- Water Heating
- Lighting
- Appliances & Electronics
- Demand Response

Advanced Transportation

- Propulsion Systems
- Vehicle Design & Materials
- Freight Logistics
- Land Use & Infrastructure Design
- Enabling IT

Advanced Industry

- Manufacturing Machinery & Process Equipment
- Industrial CHP

METHODOLOGY

The first attempt to quantify the size of the global and U.S. advanced energy markets was *Economic Impacts of Advanced Energy*, prepared by Pike Research (now Navigant Research) and published in January 2013. *Economic Impacts of Advanced Energy* presented revenue data across the 41 subsegments of advanced energy for 2011 and estimates for 2012. Beginning with *Advanced Energy Now 2014 Market Report*, Navigant Research has continued to track global and U.S. advanced energy revenue. *Advanced Energy Now 2019 Market Report* contains final annual revenue from 2011 to 2017 and estimated revenue for 2018 to provide both a snapshot of market size at the present time and growth trends over the past seven years.

Advanced Energy Now 2019 Market Report draws on more than 60 previously published Navigant Research studies on specific industry categories for the most comprehensive assessment of advanced energy markets to date. However, the results presented in *Advanced Energy Now 2019 Market Report* must be viewed as a conservative assessment of advanced energy market size. Though this is the most comprehensive study yet performed, it is not exhaustive, due to limitations in available data, and it is purposely conservative in methodology:

- Identified subsegments or product categories that have not been independently studied by Navigant Research are not included, leading the size of some segments to be significantly understated.
- The market revenue for most subsegments is based on the total installed cost of the technology. However, some subsegments only measure vendor revenue from equipment sales excluding revenue from installation and other services, and other subsegments exclude revenue from multiyear projects still in development.
- The focus of the market data is primarily on new investments, capital improvements, and the sale of products and services – not, for example, the sale of electricity generated by installed technologies in the Advanced Electricity Generation segment. Sales of advanced fuels such as ethanol and biodiesel, however, are included in the Advanced Fuel Production segment.
- In some product categories, such as Hydropower, Nuclear, and Gas Turbines, projects can take between two and 10 years to complete, making tracking of annual capital investment difficult. For this analysis, the full total installed plant cost was assigned to the year in which orders were placed for the main components (e.g., turbines, reactor, generator equipment).
- Operations and maintenance revenue is not included, nor is refurbishment revenue, which can be substantial for certain subsegments.
- U.S. market revenue counts only domestic sales of advanced energy products and services and does not include revenue from exports,

understating the economic scope of the U.S. advanced energy industry.

It should also be noted that Navigant Research has utilized strict definitions within product categories, in order to distinguish advanced energy from conventional energy products. For instance, in the Building Efficiency segment, not all HVAC installations are counted, only HVAC installations associated with energy-specific commercial retrofits, new HVAC systems that exceed local code compliance, ground-source heat pumps, and systems deployed in high-efficiency homes. The parameters for advanced water heating are even more restrictive: This category includes only residential water heating as specifically used in high-efficiency homes. For more detailed information on individual subsegments and product categories, see *Economic Impacts of Advanced Energy*. Also, for a more complete picture of 52 individual technologies and products, in terms of description, current deployment, and economic and system benefits in the United States, see AEE's technology catalogue, *This Is Advanced Energy*.

It is the goal of the annual *Advanced Energy Now* market reports to include new data as they become available, in order to better characterize the true scope of advanced energy markets. Thus, some editions have quantified product categories that were not included in *Economic Impacts of Advanced Energy* or in prior editions of the market report. In cases where that has occurred, revenue from the new categories has been included in data tables for the years those data are available. For that reason, care must be taken in comparing results from different years.

In *Advanced Energy Now 2019 Market Report*, growth rates between 2011 and 2018 are calculated (and depicted in accompanying graphs) using only those product categories for which market data are available for all years. No new products or categories have been added since 2014, so 2014, 2015, 2016, 2017, and estimated 2018 revenue are directly comparable for all segments and sub-segments.

OVERVIEW & SUMMARY FINDINGS

Advanced energy revenue reached nearly $1.6 trillion worldwide in 2018, an increase of 4% over 2017, following growth of 7% the year before. Since Navigant Research started tracking for Advanced Energy Economy in 2011, **global advanced energy revenue has risen at a Compound Annual Growth Rate (CAGR) of 4%.** Advanced energy revenue is now equal to the global tourism industry,[1] greater than pharmaceutical spending worldwide,[2] and double the global airline industry.[3] (Figure 1)

Global Revenue by Industry

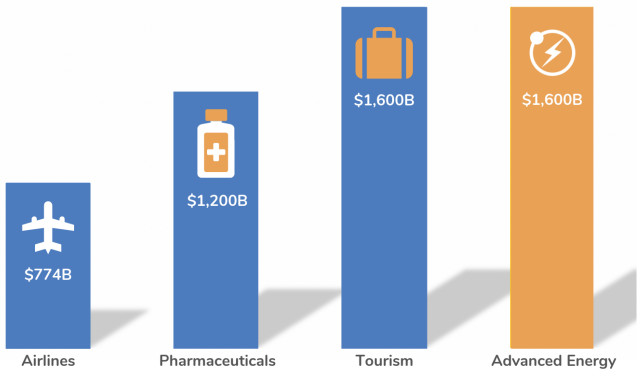

Figure 1

[1] IBISWorld, https://www.ibisworld.com/industry-trends/global-industry-reports/additional-reports/tourism.html

[2] PharmTech.com, http://www.pharmtech.com/global-medicine-spending-top-15-trillion-2023-0

[3] IBISWorld, https://www.ibisworld.com/industry-trends/global-industry-reports/transport-post-storage/airlines.html

GLOBAL ADVANCED ENERGY MARKET

$495 BILLION
advanced transportation

$453 BILLION
advanced electricity generation

$298 BILLION
building efficiency

$160 BILLION
advanced fuel production

$135 BILLION
electricity delivery and management

$54 BILLION
advanced industry

$991 MILLION
advanced fuel delivery

Global Advanced Energy Revenue (million $)

Subsegment	2011	2012	2013	2014	2015	2016	2017	2018 estimate
Advanced Transportation	325,914	315,865	343,577	365,095	413,486	446,989	483,721	494,764
Advanced Fuel Production	110,667	138,644	141,855	148,062	121,926	118,086	144,634	160,059
Advanced Fuel Delivery	2,207	1,926	2,606	2,718	900	953	993	991
Building Efficiency	118,055	133,839	147,339	208,228	236,494	271,588	273,345	298,478
Advanced Industry	4,202	5,452	6,733	7,186	7,703	8,283	48,821	54,487
Advanced Electricity Generation	461,729	408,674	333,882	404,428	432,464	455,582	454,218	452,987
Electricity Delivery & Mgt	50,782	76,834	77,610	84,737	97,651	99,113	127,259	135,062
Total	1,099,930	1,109,107	1,085,364	1,254,095	1,346,324	1,436,237	1,532,992	1,596,828

Table 1 (Navigant Research)

Globally, the biggest revenue increase among the seven segments of advanced energy came in Building Efficiency, up $25 billion (9%) to nearly $300 billion in 2018. This growth was led by high-efficiency Heating, Ventilation, and Air Conditioning (HVAC), up 10% over 2017. High-efficiency Lighting, the largest category of Building Efficiency, was up 4% in 2018, after 7% growth the year before.

The fastest-growing segment globally was Advanced Industry, up $5.7 billion, or 12%, to $54.5 billion. Revenue from Industrial Energy Management Systems was up 19%, to $21.6 billion, following 23% growth the prior year. Industrial Combined Heat and Power (CHP) was up 7%, to $32.9 billion.

Advanced Fuel Production also saw a big increase in 2018, up $15.4 billion, or 11%, to $160 billion globally. It has been two big years for biodiesel – up 27% in 2018, to $30.5 billion, following 20% growth in 2017. CNG/LNG also had a big year in 2017 – 27% growth – then up 6% in 2018, to $77.3 billion. Ethanol also had a strong 2017, up 17%, followed by 7% in 2018, to $46.3 billion.

Advanced Transportation grew 2% in 2018 after 8% growth in 2017, at which point it overtook Advanced Electricity Generation to become the largest segment of advanced energy revenue worldwide. At $495 billion, Advanced Transportation has seen huge growth in Plug-in Electric Vehicles (PEV) in the past two years – up 69% in 2017 and 49% in 2018, reaching $77.5 billion. But the largest

product category, Clean Diesel Vehicles, has been in decline since its 2016 peak, with revenue falling 2% in 2017, then 12% in 2018, to $263 billion worldwide.

Advanced energy revenue has grown even faster in the United States than globally, up 11% over 2017 – nearly four times the growth rate of the U.S. economy overall – and 8% the previous year. At $238 billion, U.S. advanced energy revenue is roughly equal to aerospace manufacturing[4] and double the biotechnology industry.[5] (Figure 2) **Since 2011, U.S. advanced energy revenue has grown at CAGR of 6%.**

The bulk of the $25 billion U.S. revenue growth came in three segments: Advanced Transportation (up $7.9 billion), Building Efficiency (up $7.8 billion), and Fuel Production (up $5.4 billion). (Table 2)

U.S. Revenue by Industry

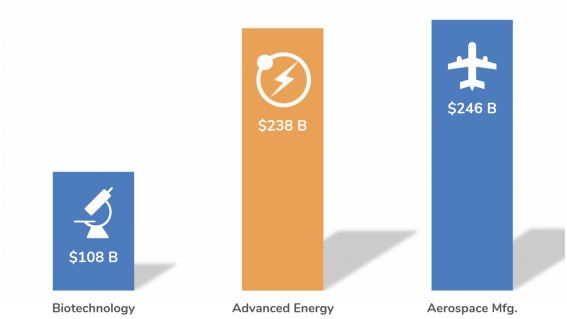

Figure 2

[4] Bureau of Economic Analysis, https://apps.bea.gov/iTable/iTable.cfm?reqid=56&step=2&isuri=1#reqid=56&step=2&isuri=1

[5] IBISWorld, https://www.ibisworld.com/industry-trends/market-research-reports/healthcare-social-assistance/social-assistance/biotechnology.html

U.S. ADVANCED ENERGY MARKET

$83 BILLION
building efficiency

$59.6 BILLION
advanced electricity generation

$33.4 BILLION
advanced fuel production

$31.2 BILLION
advanced transportation

$21.3 BILLION
electricity delivery & management

$9 BILLION
advanced industry

$168 MILLION
advanced fuel delivery

U.S. Advanced Energy Revenue (million $)

Subsegment	2011	2012	2013	2014	2015	2016	2017	2018 estimate
Advanced Transportation	11,709	18,045	25,106	24,848	22,933	21,820	23,336	31,282
Advanced Fuel Production	43,164	47,337	48,390	49,048	35,708	28,944	29,731	33,423
Advanced Fuel Delivery	227	378	252	283	186	178	160	168
Building Efficiency	35,319	39,314	43,781	57,746	63,736	68,826	75,255	83,053
Advanced Industry	4,202	5,452	6,733	7,186	7,703	8,283	9,082	9,044
Advanced Electricity Generation	38,813	43,943	30,404	44,537	48,280	52,187	55,288	59,601
Electricity Delivery & Mgt	12,205	19,211	18,859	19,256	18,471	18,982	21,598	21,311
Total	145,639	173,680	173,525	202,904	197,016	199,221	214,449	237,882

Table 2 (Navigant Research)

Advanced Transportation saw both the largest increase and the fastest growth year over year (34%). Leading this growth was revenue from PEVs, up 75% from 2017, to $18 billion. Indeed, PEV growth has been explosive, with compound annual growth (CAGR) of 59% since 2011. In past years, some PEV growth has apparently come at the expense of hybrid vehicles, which peaked at $15 billion in 2013. But based on the past three years, revenue from hybrids seems to have settled in at about $9 billion annually.

Building Efficiency – the largest segment of U.S. advanced energy revenue – saw 10% revenue growth in 2018, continuing its streak of year-over-year increases. Counting only products for which we have eight years of data, Building Efficiency has grown at a CAGR of 11% since 2011. High-efficiency Lighting is still the largest subsegment of Building Efficiency, totaling $30 billion in 2018, and still growing, up 6% over 2017.

U.S. Advanced Fuel Production staged a comeback in 2018, growing 12%, to $33.4 billion. With sharp declines in 2015 and 2016 from previous near-$40 billion levels, Ethanol fuels have been a drag on overall U.S. advanced energy growth. But in 2018, Ethanol

rebounded, up 11% to $22.4 billion, thanks to an uptick in price. Meanwhile, Biodiesel fuels had their biggest year since we have been tracking it – up 43%, to $7.3 billion, thanks to retroactive extension of a biodiesel tax credit, anti-dumping actions taken by the federal government, and an increase in price.

Advanced Electricity Generation revenue also grew in 2018, up 8% to $59.6 billion. This segment has grown every year but one since 2011, for a CAGR of 6%. Revenue from Wind installations was up 23%, to $14 billion, after a dip of 19% in 2017. After years of boom and bust – due to an on-again, off-again federal production tax credit (PTC) finally extended for five years with a scheduled phase-out – Wind has held relatively steady, at roughly $14 billion in annual revenue since 2015.

Solar PV revenue was up 8% over 2017, at $24.2 billion, even as unit costs continued to fall, and nearly returning to its 2016 boom-year peak of $24.9 billion. While Solar PV revenue increased 8% in 2018, installed capacity grew 14%. Solar PV revenue has grown at CAGR of 17% since 2011. Meanwhile, Concentrating Solar had a bit of a comeback, with revenue of $1.5 billion in 2017 and $1.3 billion in 2018, after registering zero in 2015 and 2016. Combined Cycle Gas Turbines also had relatively strong years in 2017 and 2018 – $12.9 billion and $13.2 billion respectively, up from $8 billion in 2016.

At $21.3 billion, Advanced Electricity Delivery and Management revenue was flat overall, but showed notable growth in certain categories. Energy Storage revenue was up 18%, to $701 million, after even bigger growth years in 2016 (54%) and 2017 (39%). Electric Vehicle Charging Infrastructure was up 23%, to $280 million, following a similar jump in 2017. Revenue from Smart Meters, sales of which had been slow following federal Recovery Act-related spending early in the decade, turned around in 2017, jumping 81% to $1.2 billion, before declining 6% last year. Still, at $1.1 billion in 2018, Smart Meters were within shouting distance of the 2011 and 2012 peak of $1.4 billion.

BUILDING EFFICIENCY

$83.8 BILLION

U.S. revenue

10%

annual growth

$298.5 BILLION

global revenue

9%

annual growth

Overview

Consistently the most reliable growth segment of advanced energy globally and in the United States, Building Efficiency continued to grow in 2017 and 2018, spurred by technology innovation, government climate and greenhouse gas (GHG) reduction requirements, and a move toward business models that produce recurring revenues. **Globally, revenue reached $298.5 billion in 2018 after growing 9% from 2017 to 2018 and 1% from 2016 to 2017. In the United States, Building Efficiency revenue grew to $83 billion, up 10% from 2017, following an increase of 9% the year before.** Counting only products for which we have data for all years, U.S. Building Efficiency revenue more than doubled from 2011 to 2018, for Compound Annual Growth Rate (CAGR) of

11%, while global revenue has more than tripled over the seven years, also for CAGR of 11%.

Globally, climate targets and consumption regulations adopted by national and local governments continue to drive adoption of efficient and intelligent building technologies. Buildings account for about one third of total global final-use energy, over half of electricity demand, and just under 10% of energy-related CO_2 emissions.

Lighting remained the largest subsegment with $139.5 billion in revenue in 2018, up 4% from 2017, following 7% growth the year before. (Table 3) Since the commercialization of LED lighting technology, the growth of energy efficient lighting has been extraordinary. However, a greater penetration of the installed base and declining prices are beginning to temper the sustained double-digit growth the segment has experienced.

In other notable categories, revenue from Smart Appliances has begun to take off. Up 55% 2016 to 2017 and 60% last year, this small but growing product category reached $7.5 billion globally in 2018.

Global Building Efficiency Revenue (million $)

Subsegment	2011	2012	2013	2014	2015	2016	2017	2018 estimate
Building Design	11,537	13,039	13,932	15,544	17,457	19,021	21,180	23,605
Building Envelope	13,017	14,006	15,855	18,668	26,187	44,960	25,676	28,962
HVAC	44,383	49,613	53,923	57,962	62,337	65,820	71,489	78,592
District Energy and CCHP	2,229	2,787	3,023	2,950	3,458	3,875	4,291	4,834
Water Heating	1,467	1,612	1,773	2,090	2,237	2,438	3,182	4,774
Lighting	41,329	47,212	52,770	103,613	116,498	124,782	133,561	139,473
Appliances	266	613	800	1,200	1,708	3,018	4,676	7,481
Demand Response & Enabling IT	3,827	4,957	5,262	6,200	6,612	7,675	9,291	10,757
Total	**118,055**	**133,839**	**147,339**	**208,228**	**236,494**	**271,588**	**273,345**	**298,478**

Table 3 (Navigant Research)

Intelligent building technologies are providing new and less expensive avenues to make buildings more efficient. Better collection and analysis of building data promises to improve efficiency and lead to significant energy savings. Almost every technology group utilized in energy efficient building projects, from HVAC systems to the building envelope, has been affected by digital control and optimization. This digital incursion has transformed many of the technologies and opened opportunities to realize greater whole-building efficiency and energy cost savings. The spreading adoption of these technologies

can be seen in the growth of Demand Response & Enabling IT revenue, of which building management systems make up the bulk of revenue. **Globally, revenue from Building Energy Management Systems grew 16% from 2016 to 2017 and 21% last year, reaching $4.4 billion in 2018.** Home Energy Management Systems revenue grew 15% last year after 35% growth 2016 to 2017, reaching $3.6 billion in 2018.

U.S. Building Efficiency Revenue (million $)

Subsegment	2011	2012	2013	2014	2015	2016	2017	2018 estimate
Building Design	2,819	3,128	3,351	3,850	4,336	4,711	5,279	5,884
Building Envelope	8,720	9,645	11,919	12,766	14,127	14,920	16,215	17,907
HVAC	10,522	11,532	12,306	13,184	14,140	15,233	16,433	17,860
District Energy and CCHP	814	925	1,189	850	925	1,055	1,120	1,193
Water Heating	1,133	1,197	1,357	1,490	1,639	1,711	2,127	2,960
Lighting	9,139	9,992	10,701	22,024	24,666	26,351	28,338	30,010
Appliances	105	148	208	227	472	887	1,375	2,040
Demand Response & Enabling IT	2,068	2,748	2,748	3,356	3,431	3,959	4,370	5,198
Total	35,319	39,314	43,781	57,746	63,736	68,826	75,255	83,053

Table 4 (Navigant Research)

In the United States, Building Efficiency accounts for $83 billion of revenue and has grown consistently since AEE began tracking in 2011, with total revenue more than doubling over that time. (Table 4) Building Efficiency revenue has grown at a compound annual rate of 13% from 2011 to 2018.

The regulatory environment has undergirded much Building Efficiency growth. While appliance standards and some tax incentives are set by the federal government, energy efficiency policy is mostly set at a state level, via building codes and utility-administered incentive programs.

However, recent growth in Building Efficiency is also being driven by new offerings enabled by the evolution of the built environment. Building digitization has enabled greater access to data and information that now spans the organization from operations to the C-level, proving deeper insights for understanding and managing the business better, tracking and promoting sustainability initiatives, and improving internal operations. This digitalization, in turn, has helped services

provided by efficiency vendors gain market traction and increased presence in commercial and residential buildings.

Financing Aids Energy Efficiency Growth

Historically, financing energy efficiency initiatives has posed major challenges to the building industry. Lack of access to capital is often cited as a major barrier to the more widespread adoption of energy efficiency. Today, there are an increasing number of sources of capital for energy efficiency, including the greater adoption of as-a-service delivery models, which keep project expenses off of business's balance sheets.

Spending per Capita on Energy Performance Contracts by State, United States, 2017

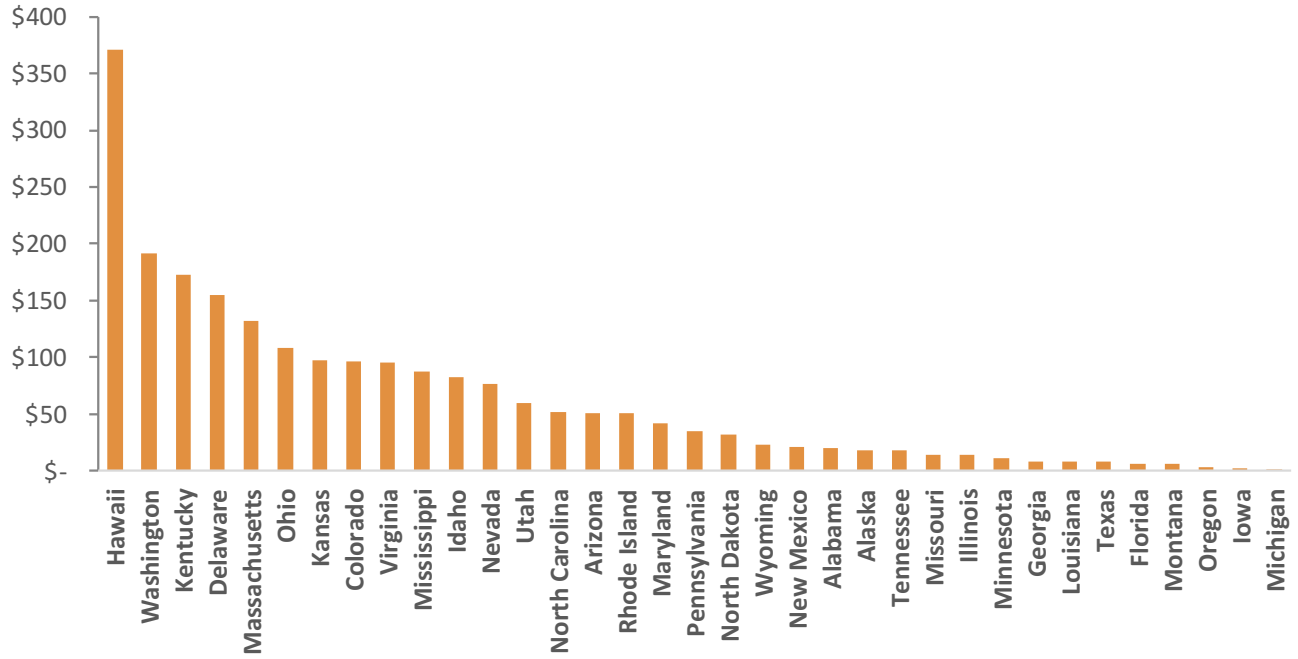

Figure 3 (Navigant Research)

Energy service companies (ESCO) have been instrumental in providing access to energy efficiency technologies and services in market segments that would not normally be able to consider or afford these types of capital-intensive projects. By using energy performance contract (EPC) or energy savings performance contract (ESPC) financing

structures, ESCOs remove the financial risk of the project for an end-use customer. Specifically, municipal, university, school, and hospital institutions have taken advantage of the opportunity to save on energy costs via ESPCs. (Figure 3)

As a result, U.S. revenue from ESCO services has grown 46% from 2011 to 2018, with increases of 8% in each of the past two years, reaching $868 million in 2018. (Figure 4)

U.S. ESCO Services, 2011-2018

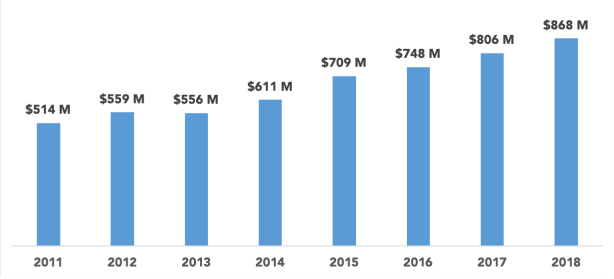

Figure 4 (Navigant Research)

Energy efficiency in buildings is also converging with the broader mix of distributed energy resource (DER) technology and software solutions that are disrupting traditional utility electricity procurement and delivery models. A broader competitive environment is emerging consisting of a disparate set of third-party vendors, utility services companies, and new entrants deploying niche technical, financing, or procurement solutions, energy services performance contracts, and deregulated electricity market retail brokerage services. Financing innovation sits at the heart of this Energy-as-a-Service (EaaS) shift and enables the delivery of building efficiency as a new utility customer choice option.

Lighting Shifts to Controls

Lighting has historically been the low hanging fruit of efficiency in commercial buildings, since lighting upgrades are cheaper than other efficiency improvements, such as an updated HVAC system or building energy management system. In 2018, as in every year since 2014, Lighting provides the largest share of U.S. Building Efficiency revenue, at $30 billion.

LEDs have experienced a continual price decline each year, making them more competitive with other lighting technologies. This trend, coupled with increased lifespan, improved efficiency, and superior controllability (which allows integration with lighting controls), has primed LEDs to become the leading lighting technology. Although reducing energy costs has been the primary driver for adoption, better light quality, longer lifespans, and improved controllability have helped push LED adoption.

However, the longer lifespan of an LED is leading to a plateau in revenue growth due to slower replacement cycles. As was seen in global Building Efficiency, annual growth in U.S. Lighting revenue overall has come down to single digits: 8% from 2016 to 2017; 6% 2017-2018. As a result, many lighting vendors are expanding into control products as an alternative revenue source. U.S. revenue from Intelligent Lighting Controls has grown at double-digit rates each year since 2011, with growth of 17% 2016 to 2017, 15% last year. Intelligent Lighting Controls accounted for $1.6 billion of U.S. revenue in 2018, up 122% from 2011. (Figure 5)

Lighting Revenue by Segment, United States: 2014-2018

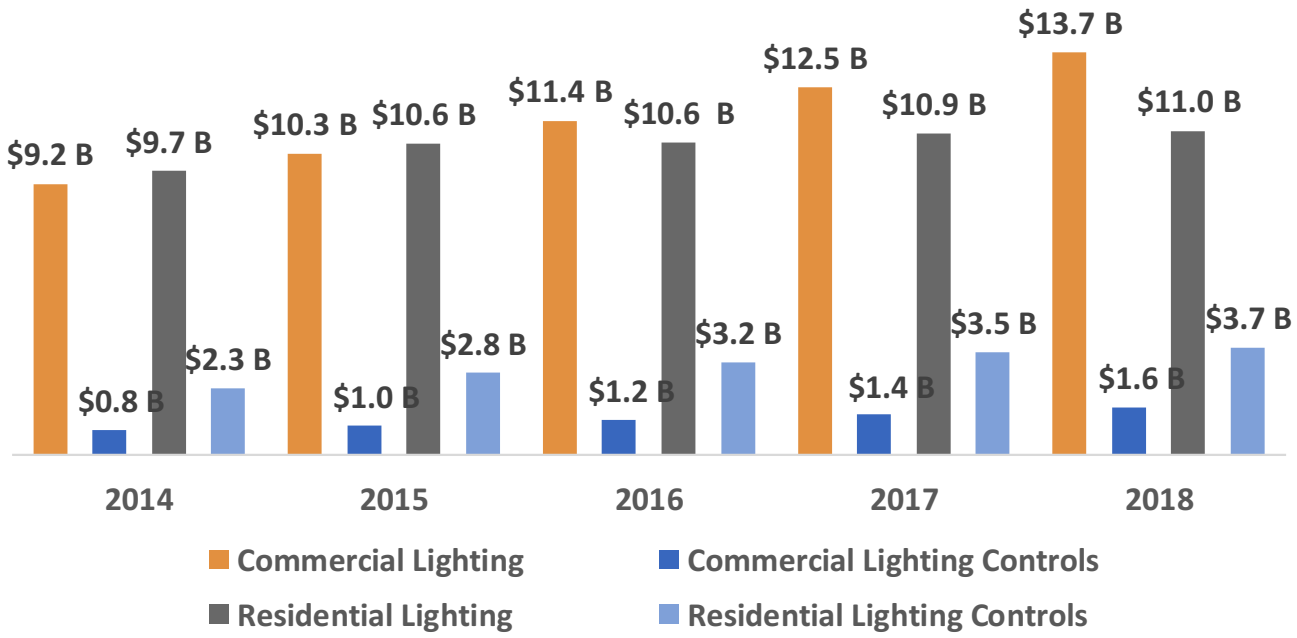

Figure 5 (Navigant Research)

Several market sectors are showing high interest and increasing demand for intelligent lighting products: Retailers are using intelligent lighting systems to mesh the online and offline (in-store) customer experience with innovative use cases. Health care facilities are utilizing intelligent lighting systems to make the physical environment part of the patient healing process, as well as increasing the efficiency and safety of hospital staff.

Additionally, indoor positioning systems (IPS) that use connected lighting systems are gaining traction. While location-based services and mapping via global positioning systems (GPS) are commonplace in the outdoor environment, these functionalities have not always been available indoors. There are various technologies that enable IPS, ranging from Wi-Fi to Bluetooth beacon technology. Visible light communication (VLC) and Bluetooth Low Energy (BLE) are the two most common technologies available for a lighting-based IPS.

VLC is an advanced communication technology using visible light. Data is communicated wirelessly when a light is switched on and off and received by a transmitting device. This data is fed to a light bulb using signal processing technology, including a pulse generator and modulator. From there, the data is embedded in the light beam and sent at rapid speeds to the receiver.

The receiver contains a photodetector with a photodiode that converts light into current. The data is also sent through a signal filter and conditioner and a demodulator that converts the current output into a pulse signal.

The most notable use of lighting-based IPS is in the retail segment. For this use case, VLC often works in conjunction with BLE. Indoor positioning using VLC and/or BLE is obtained by a building owner or manager using LED lighting that is VLC software-enabled or that incorporates a BLE beacon. A retail customer downloads an app that allows the VLC software to connect to the user's smartphone camera to access their location. In the case that only BLE is used, permission of a user's smartphone camera is not required. The ability to pinpoint the exact location of a customer and provide them with targeted coupons, product information, reviews, or in-store help by a sales associate offers an improved shopping experience. This experience is also more comparable to online shopping, where additional product information and discounts are a click away.

Smart Appliances Poised for Growth

Smart appliances refer to major household appliances or white goods that have communicating capabilities to send and receive data to a hub or cloud service for ongoing monitoring and control. The benefit of smart appliances can vary from the ability to remotely view refrigerator contents via connected camera to automatically running clothes washers and dryers during times when electricity prices are cheaper.

For years, the smart appliances market has been waiting in the wings for a "connected home" revolution that had yet to materialize. Few buyers were willing to pay a premium for major appliances embedded with high tech capabilities and internet connectivity when the benefits provided by the refrigerator, washer, or dryer on its own were either unclear or minimal.

Connected Devices in the Smart Home

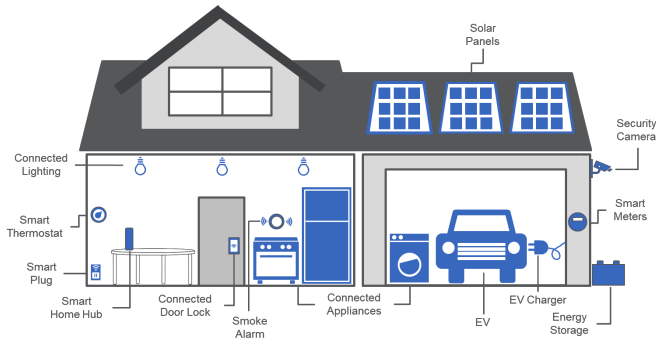

Figure 6 (Navigant Research)

But a recent wave of adoption of smart home products has occurred among consumers seeking greater automation, energy savings, and convenience in their homes. Products like smart thermostats, connected lights controlled by voice activation, and smart locks have gained a foothold among consumers. **Home Energy Management Systems has been one of the fastest growing categories in Building Efficiency since 2011, reaching $1.8 billion in 2018 on 10% annual growth, after 32% growth from 2016 to 2017.** This has set the stage for smart appliances to take off – and there are signs that they are poised to do so.

ELECTRICITY DELIVERY & MANAGEMENT

$21.3 BILLION

U.S. revenue

-1.3%

annual growth

$135.1 BILLION

global revenue

6%

annual growth

Overview

Of all the segments covered, the market for **Electricity Delivery and Management products and services recorded the highest compound annual growth rate (CAGR) in the period 2011 to 2018 worldwide (12%); in the United States, CAGR was 4% over that time period.** The year 2017 was one of the biggest for electricity delivery and management, recording 28% growth globally and 14% in the United States. While the market plateaued somewhat in 2018, with global growth at 6% and a slight decline in U.S. revenue, Electricity Delivery and Management products will continue to receive significant investment in the next decade. **The fastest growth over the period has been in**

EV Charging Infrastructure and Energy Storage. These markets started at a low base, but revenue has multiplied eight-fold over the seven-year period, recording double-digit gains in 2017 and 2018 in both U.S. and world markets.

Global Electricity Delivery and Management Revenue (million $)

Subsegment	2011	2012	2013	2014	2015	2016	2017	2018 estimate
Transmission	25,180	29,325	28,145	31,827	41,242	36,110	51,958	55,389
Distribution	5,998	7,383	7,828	8,459	9,186	7,552	8,552	9,531
AMI	6,273	6,514	5,805	5,835	7,654	10,054	10,865	13,072
Microgrids	3,737	4,400	5,479	7,087	5,284	6,835	10,234	7,170
Charging Infrastructure	127	355	417	480	511	864	3,032	3,790
Energy Storage	117	791	646	462	889	1,289	1,850	2,403
Enabling ICT	9,351	28,066	29,289	30,588	32,884	36,410	40,767	43,707
Total	**50,782**	**76,834**	**77,610**	**84,737**	**97,651**	**99,113**	**127,259**	**135,062**

Table 5 (Navigant Research)

Total revenue in this market is primarily driven by large-scale transmission infrastructure and the enabling information & communications technology (ICT) that supports grid management. These areas are both mature but growing strongly in recent years. There are many drivers for this growth. For example, grid-scale renewables require investment in transmission systems to transport power from remote locations to the point of consumption.

At $55.4 billion worldwide, transmission is the largest subsegment of Electricity Delivery and Management. (Table 5) When markets are this big, it is not unreasonable to expect slow, steady growth. As transmission projects often involve large investments, it is also not unusual to see big year-to-year swings, as we saw between 2011 and 2014. **But overall, global growth has been impressive, with 12% compound annual growth over the seven-year period, with particularly big years in 2017 and 2018.**

In the United States, with the exception of microgrids, CAGR for each of the subsegments in Electricity Delivery and Management has been lower than global growth over this period. Still, **4% compound annual growth for U.S. Electricity Delivery and Management overall indicates strong demand.** The U.S. market for these goods and services is growing; other markets are just growing faster.

Energy policy in most countries is set at a federal level, and in the case of Europe, can be significantly affected by the supranational policies of the European Union, which is investing aggressively in energy transition. In the United States, most energy policy is made at a state level. Across the 50 states there are widely different approaches to each, with a handful of states, including California, New York, and Hawaii, blazing an ambitious trail with respect to overall advanced energy deployment and regulatory transformation. Still, considering the infrastructure investments being made in emerging markets like India and China, it is no surprise that the United States, while still an attractive market, is growing less rapidly.

It is noteworthy that **Advanced Metering Infrastructure (AMI) had big revenue years in the United States in the past two, jumping 65% in 2017, to $1.4 billion, and holding roughly steady in 2018.** (Table 6) AMI revenue had been tapering off from the 2011-12 level of nearly $1.7 billion a year, when these utility investments were driven by the federal American Recovery and Reinvestment Act, reaching a low of $860 million in 2016. But in the past two years, AMI deployment has had a bit of a revival.

U.S. Electricity Delivery and Management Revenue (million $)

Subsegment	2011	2012	2013	2014	2015	2016	2017	2018 estimate
Transmission	5,298	7,317	7,750	7,978	7,219	6,812	7,289	6,778
Distribution	1,064	1,205	1,337	1,621	1,481	1,295	1,409	1,474
AMI	1,648	1,681	1,387	1,193	1,051	861	1,418	1,361
Microgrids	1,012	1,265	1,623	1,957	1,893	2,196	2,817	2,496
Charging Infrastructure	27	92	154	157	164	182	228	280
Energy Storage	81	360	519	58	277	427	593	701
Enabling ICT	3,075	7,291	6,089	6,293	6,386	7,209	7,843	8,222
Total	12,205	19,211	18,859	19,256	18,471	18,982	21,598	21,311

Table 6 (Navigant Research)

Energy Storage Continues to Take Off

Both globally and in the United States, energy storage continues to gain traction in the marketplace. Worldwide revenue for energy storage has grown from $462 million in 2014 to $2.4 billion in 2018. **In the United States, energy storage revenue has climbed from $58 million to $701 million over the past five years.** (Figure 7)

Over the past year, renewables plus storage projects were largely the driving force behind new announcements. One of the more interesting projects announced in 2018 was a lithium ion (Li-ion) battery being developed at India's first-ever wind and solar hybrid project. Hero Future Energies (the owner/operator of the project) stated that the hybrid plant has seen extremely good wind production and consequently must curtail solar because of capacity constraints on the local grid. The Li-ion battery will help mitigate the need for curtailment. Hero states that this will act as a pilot project; if all goes as planned, then the company will retrofit older renewable projects as well as include a storage component in all new projects.

U.S. Energy Storage Revenue, 2014-2018

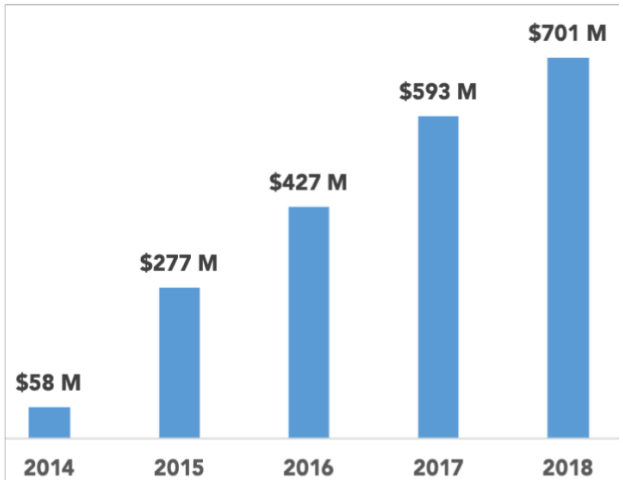

Figure 7 (Navigant Research)

Traditional generation replacement is also a key driver for utility-scale storage. One of the most notable tenders this year was Pacific Gas and Electric's (PG&E's) solicitation for energy storage to replace three power plants in its service territory. The gas-fired plants it is replacing had operated as reliability-must-run resources. Deploying strategically located energy storage will help lower operating costs and address congestion issues in the region.

Distributed energy storage systems continue to grow slowly throughout global markets, accounting for 23% of new capacity announced in 2018 (excluding pumped storage). These systems are frequently paired with other generating assets (renewable or otherwise) and are chiefly used for applications like demand charge management, peak shifting, and resilience/backup power.

Charging Infrastructure Paves the Road for EVs

In 2011, few predicted quite how soon EV adoption would occur. Few auto manufacturers were building battery-powered vehicles, and most of these were hybrids that used a gasoline engine to charge batteries rather than the electricity grid. However, since 2011 the EV market has grown rapidly. Barriers to widespread adoption remain, among them so-called range anxiety – how far EVs can travel before refueling. Battery technology continues to improve, allowing for cars that are able to travel further on one charge. (See Advanced Transportation.) Another necessity for relieving range anxiety is the deployment of charging infrastructure, including DC fast charging.

While there is a strong argument for a "build it and they will come" approach to EVs and charging infrastructure (the more charging stations deployed, the more consumers will buy EVs), the approach to date has been more

"wait and see." The industry has now passed the tipping point, though: Sufficient investors now believe that EVs are a reality and are mobilizing to deploy charging stations.

There are many parties interested, including major oil companies, which are starting to get involved in EV charging. For utilities, EVs present the largest opportunity for load growth in a generation. Municipal, regional, and national governments are driving EV adoption, and are incorporating EV charging networks in their long-term transportation plans. Major equipment providers are focused on the charging market, including Siemens, Schneider Electric, and ABB, while private charging networks like EVgo are expanding rapidly. The market for EV charging infrastructure really took off in 2017, driven by an increase in EV models and charging developments such as ultrafast charging (UFC), a high-powered version of DC Fast Charging. Since 2017, there has been an increase in the number of companies developing and producing UFC equipment. UFC provides over 150 kW of power output from a charging port. A significant degree of attention is now focused on fast charging corridors that enable long-range all-electric driving. Governments in leading national markets – the United States, Norway, the Netherlands, Denmark, and South Korea – have been influential in spurring automakers and the charging industry to begin incorporating ongoing advances in equipment in existing and future fast-charging networks.

While growing at a rapid rate, the Charging Infrastructure market in the United States is just catching up to the rest of the world. Whereas worldwide revenue from Charging Infrastructure took a 250% leap in 2017, reaching $3 billion, U.S. revenue increased just 25%, to $228 million. Growth globally and in the United States largely tracked in 2018, at roughly 25%. (Figure 8)

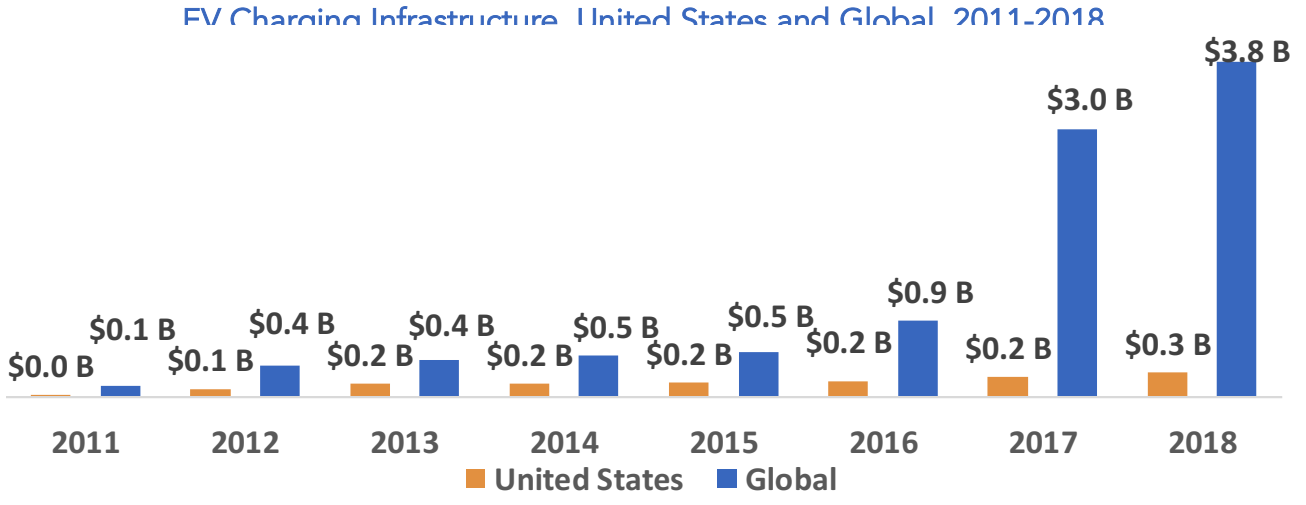

Figure 8 (Navigant Research)

Quest for Resilience Drives Microgrid Market

Often, the United States leads the world in technology adoption. However, the energy market is different. In other mature energy markets, competition among energy suppliers and more ambitious decarbonization policies are fueling more rapid investment in Electricity Delivery and Management technologies. But in the U.S. market, Microgrids are a shining light.

In 2018, U.S. revenue from microgrids was just under $2.5 billion, accounting for 35% of the global market. This is due, in part, to U.S. electricity networks being, in general, less reliable than in Europe. According to the Council of European Energy Regulators, the United States lost an average of 244 minutes per customer in 2012, compared with 95 minutes per customer in France, 81 minutes per customer in the United Kingdom, and 16 minutes per customer in Germany. Large customers such as hospitals, university campuses, and military bases are increasingly deploying microgrid technologies so that they can island themselves from the grid and become energy self-sufficient in the event of a power outage

Emerging markets have also been an area of growth for microgrids, as power grids in these markets are among the least reliable. While 2017 saw a significant increase in the adoption of microgrid technology, the market was not sustained in 2018, as deployment slipped back closer to 2016 levels. (Figure 9)

Microgrid Revenue, United States and Global, 2011-2018

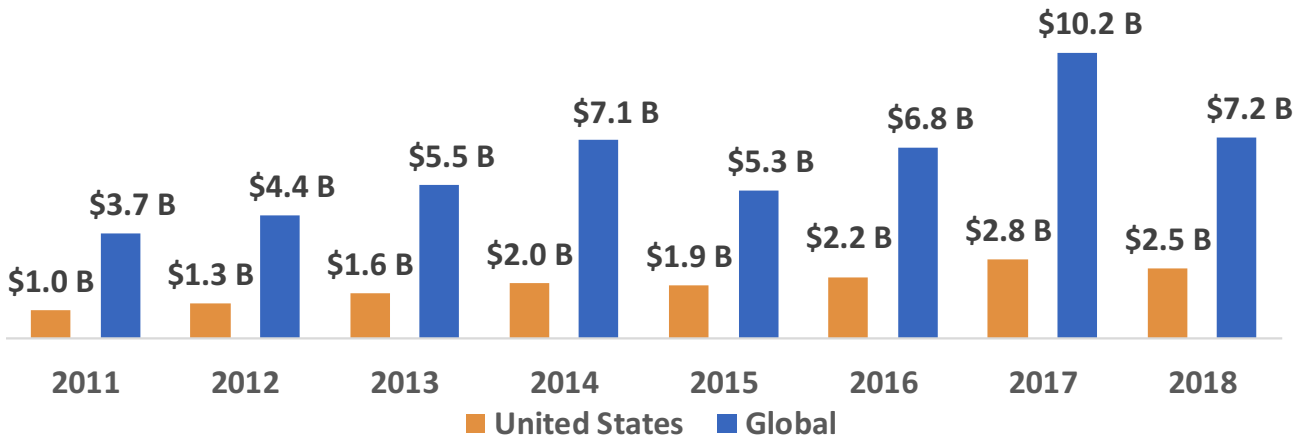

Figure 9 (Navigant Research)

One indication of the growth trajectory comes from the Microgrid Deployment Tracker, in which more than 200 new microgrids operating and under development in Q2 2018 were identified around the world. The United States remains the market leader in terms of projects currently operating and connected to a distribution grid. In addition, the remote microgrid segment has also declined as an overall portion of the total market, but some of this is due to better availability of data for grid-tied systems. It also reflects growing interest in alternative aggregation models (such as grid-dependent virtual power plants) in regions traditionally dominated by remote microgrids (such as Australia).

The microgrid market has made leaps and bounds over the past two years, particularly on controls platforms, greater interest in modular, plug-and-play offerings, and creative business models. The increase in extreme weather events, threat of wildfires, and localized phenomena such as earthquakes and volcanic eruptions all build the business case for greater energy resilience. Microgrids can serve as platforms for other services as well, including thermal energy, water, and basic telecommunications infrastructure. As a result, Navigant Research expects total microgrid capacity to grow from 3.2 GW in 2019 to 15.8 GW by 2027. (Figure 10)

Microgrid Capacity by Region, Global, 2019-2027 (MW)

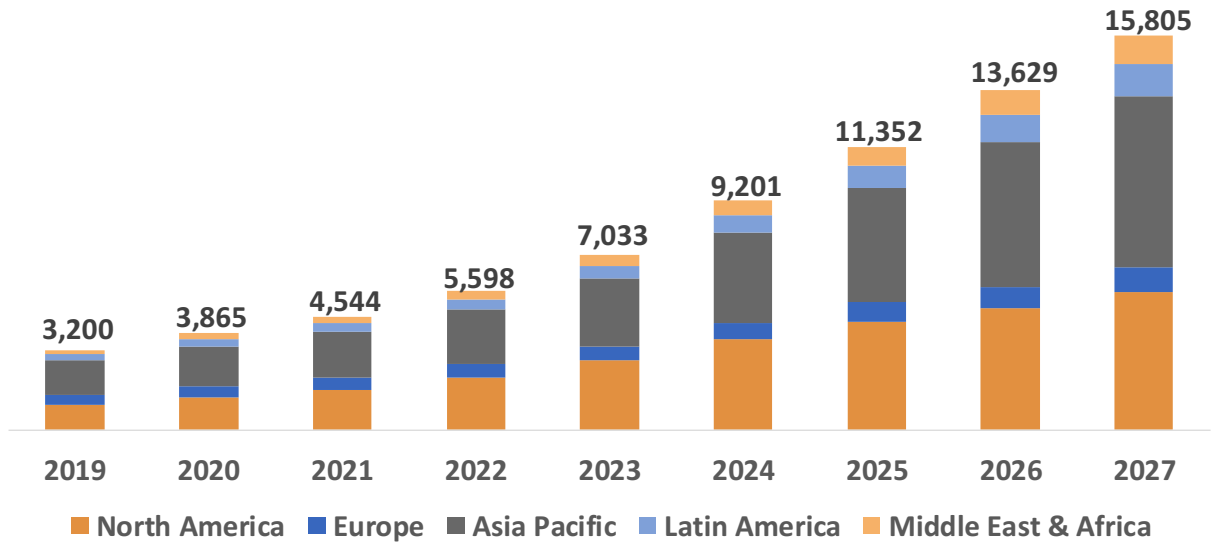

Figure 10 (Navigant Research)

ADVANCED TRANSPORTATION

$31.3 BILLION

U.S. revenue

34%

annual growth

$494.8 BILLION

global revenue

2%

annual growth

Overview

Advanced Transportation was the largest advanced energy segment worldwide in 2018 for the second year in a row, with an estimated $494.8 billion in revenue, up 2% from 2017 and 8% the year before. **Since 2011, the Compound Annual Growth Rate (CAGR) of Advanced Transportation globally was 6%.** At the end of 2018, over 5 million plug-in electric vehicles (PEVs) were on the roads worldwide. PEV sales are poised to enter a period of strong growth, driven by lower battery prices, maturing plug-in hybrid and all-electric powertrain systems, and a proliferation of new models. By the end of 2027, Navigant Research expects there to be 10 times as many PEVs on the road. **In the United States, PEV sales are surging as well, with overall Advanced Transportation revenue growing 34% year over year and accounting for nearly one-third of U.S. advanced energy**

revenue growth in 2018. Since 2011, **U.S. Advanced Transportation revenue has grown at a compound annual rate of 15%.**

Globally, Clean Diesel vehicles, both passenger cars and trucks of all sizes, still make up the bulk of the Advanced Transportation market, despite well-publicized issues (see below), though evidence suggests that a massive shift toward PEVs is under way.

At $262 billion, Clean Diesel revenue accounted for well over half of Advanced Transportation revenue worldwide in 2018, despite dropping 12% from 2017. Hybrid electric vehicles continue to grow globally, with revenue from hybrid sales up 8%, to $70 billion. **But the growth story in Advanced Transportation is in PEVs, with revenue growing 49% globally, to $78 billion, and 75%, to $18 billion, in the United States.**

Global Advanced Transportation Revenue (million $)

Subsegment	2011	2012	2013	2014	2015	2016	2017	2018 estimate
Vehicles	325,914	315,865	343,517	365,068	413,445	446,945	483,668	494,696
Vehicle Design and Materials	824	1,948	3,219	5,569	7,557	11,302	20,908	31,989
Enabling IT	NA	NA	60	28	41	44	53	68
Total	**325,914**	**315,865**	**343,577**	**365,095**	**413,486**	**446,989**	**483,721**	**494,764**

Table 7 (Navigant Research)

Light duty PEV sales experienced another record year, with over 2 million vehicles sold worldwide, including 360,000 in the United States. As of June 2018, over 40 models of battery electric vehicles (BEVs) and plug-in hybrids (PHEVs) were on the market, with many more on the horizon in the coming years. Technology advances in battery packs continue to reduce the purchase price, making more affordable PEVs, such as Tesla Model 3, Chevrolet Bolt, and Nissan Leaf, a reality.

By 2021, over 25 new BEV and PHEV crossover and SUV models are planned to be sent into production. Several, such as the Acura RDX and the Ford Escape, are existing models that will receive a BEV or PHEV model addition. Others, such as the BMW iNEXT, will be newly designed models. Tesla has stated it will add an all-electric pickup truck to its line-up of vehicles, although no release date has been announced. EV truck start-up Rivian has announced its first products and Ford has announced that it will electrify its best-selling vehicle, the F-150. Deployment of charging stations is the key element of the PEV market other than vehicles, and there the United States is playing catch-up. (See Electricity Distribution and Management for coverage of Charging Infrastructure.)

U.S. Advanced Transportation Revenue (million $)

Subsegment	2011	2012	2013	2014	2015	2016	2017	2018 estimate
Vehicles	11,709	18,045	25,075	24,839	22,919	21,805	23,321	31,263
Vehicle Design and Materials	271	488	1,217	1,763	1,393	2,261	3,143	6,317
Enabling IT	NA	NA	31	9	13	14	15	19
Total	11,709	18,045	25,106	24,848	22,933	21,820	23,336	31,282

Table 8 (Navigant Research)

In the United States, PEV sales increased 32% between 2016 and 2017 and then leapt by 75% between 2017 and 2018, reaching $18 billion in revenue. (Figure 11) Over this time, PEV sales eclipsed those of hybrid electric vehicles, as revenue from hybrids has settled around $9 billion annually, following a decline from its $15 billion peak in 2013. PEV penetration has typically clustered around urban areas in states with incentives, though a shift may be coming as the number

U.S. Hybrid and Plug-in Electric Vehicle Revenue

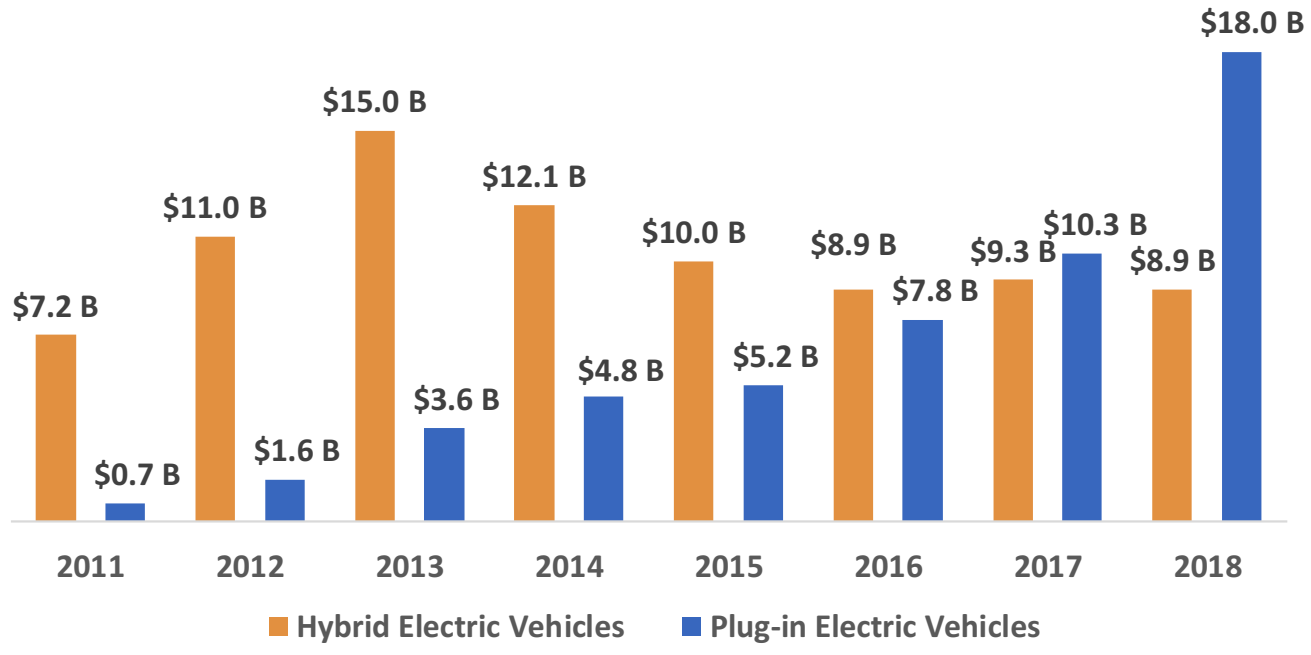

Figure 11 (Navigant Research)

of models available in showrooms around the countries increases substantially. Many U.S. states with ZEV policies, such as California and New York, continue to boast the highest sales numbers, but states like Florida and Colorado are coming to the fore in PEVs. Indeed, Colorado now has an executive order requiring adoption of ZEVs, though not yet implemented.

Electric Fleets on the Rise

PEVs for use in fleets are also on the rise in specific applications. Growth is currently concentrated in China, OECD Asia Pacific nations (Australia, Japan, South Korea, and New Zealand), North America, and Europe.

Electric Fleet Vehicles by Class, Global, 2018-2030

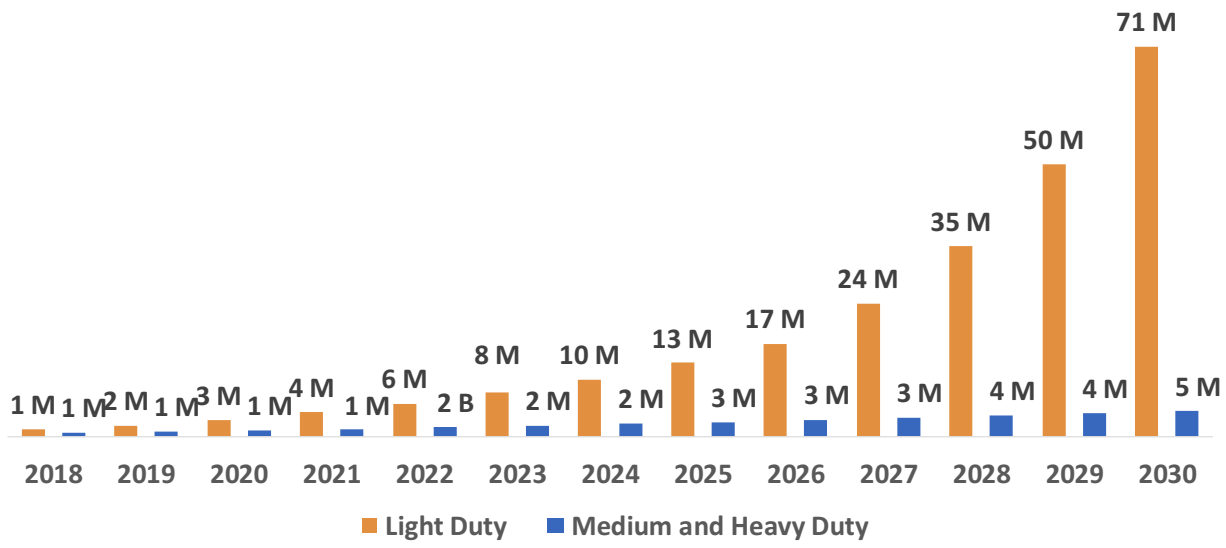

Figure 12 (Navigant Research)

In China, fleets of taxis and buses (largely state-owned) are electrifying rapidly; two-thirds of new buses in 2017 were PEVs. According to Navigant Research analysis, electric buses (including hybrid, battery electric, plug-in hybrid, and fuel cell) have already reached 16% of sales for public transit systems in the United States, as of late 2018. Fleet operators are more sensitive to vehicle economics than are individual consumers, but they are also more focused than consumers on total cost of ownership, which is more favorable for PEVs. Fleets can utilize company-owned charging depots, reducing reliance on publicly available charging stations. Over time, pairing vehicle grid integration (VGI) infrastructure technologies with fleet-owned PEVs will increase PEV payback. Companies such as UPS, FedEx, and Penske, are already actively exploring PEVs for fleet purposes.

Navigant Research estimates that PEVs made up less than 1% of the fleet vehicle market in 2018 but will rise to 12% of fleet vehicles by 2030. The light duty segment will continue to make up the majority of PEV fleet sales, but medium- and heavy-duty PEV adoption rates are expected to increase throughout the forecast period. (Figure 12)

Better Batteries Make Better Electric Vehicles

A key consideration for various PEV vehicle types is to determine which type of battery should be used in the powertrain. Early PEVs utilized sealed lead-acid (SLA) and nickel-metal hydride batteries almost exclusively, but now lithium ion (Li-ion) dominates the market because of superior energy density and rapidly falling costs.

The cost of Li-ion batteries has plunged from roughly $1,000/kWh in 2010 to between $270 and $200 in 2018. By the end of 2027, battery prices should be at levels where BEVs with ranges above 150 miles will be at cost parity with their internal combustion engine-powered counterparts. (Table 9) The cost decline will primarily be a function of leaps in battery innovation, particularly the commercialization of next generation technologies that will not only improve battery energy density but also durability.

The three emerging battery chemistries that have the greatest potential to penetrate the light duty EV market within the next five to seven years are Lithium Sulfur (Li-S), Lithium Solid-State (Li-SS), and Metal-air batteries.

Li-S batteries have long been promised as a successor to Li-ion batteries, thanks to their much higher potential energy density and the low cost of sulfur, which is the largest raw material input. However, only a few mass-manufactured, non-coin, cylindrical cell Li-S batteries are available today. These early-stage batteries have been developed for niche applications in the aviation or aerospace sectors where cycle life is not critical, but energy density and light weight is paramount These batteries typically are not capable of lasting more than 100 cycles.

Li-Ion Battery Pack Prices by Powertrain, North America: 2018 and 2027

Powertrain	Units	2018	2027
Battery Electric Vehicle	($/kWh)	$272	$180
Plug-in Hybrid Electric Vehicle	($/kWh)	$289	$151

Table 9 (Navigant Research)

The Li-SS utilizes a solid electrolyte, thereby lightening the battery, and increasing its energy density. A solid electrolyte would also eliminate the separator, reducing material and

manufacturing costs while also eliminating the risk of thermal runaway. A successful solid electrolyte battery would have greater energy density and be inherently safer than modern Li-ion batteries. The key challenge Li-SS faces is the diffusion rate of ions through the solid electrolyte, which affects the speed at which the battery can be charged and discharged.

Metal-air batteries use a metal anode, ambient air (oxygen) as the cathode, and a liquid electrolyte. Common metal-air cells include lithium-air (Li-air), sodium-air, magnesium-air, and zinc-air. Li-air has been touted as one of the most promising chemistries because of its theoretical energy density (over 3,400 Wh/kg). Key improvements that must be addressed is the tendency of the cell to form an irreversible solid electrolyte interphase film, severe dendrite formation, and material stability of the cathode.

Wireless Charging on the Horizon

Large investments are being made in wireless technology to make EV charging faster and more convenient. While the concept of wireless power transmission was first contemplated by Nikola Tesla more than a century ago, it is not until recently that advances in technology have made it practical. Nokia was one of the first to offer a mobile phone handset with wireless charging in 2012. Meanwhile, wireless charging for vehicles has been under development since before the launch of the first Nissan Leaf in 2010. After a short struggle to develop proprietary technology, the key players have been collaborating to develop industry standards, resulting in the SAE publication of a series of specifications in 2017. The first production vehicles with a wireless charging option came to market in 2018, with more on the way in 2019.

Clean Diesel Faces Uncertain Future

Nearly four years after the revelation of diesel emissions "defeat devices," governments around the world have maintained a steady stream of inquiries into diesel automaker environmental compliance. Several major cities, including Paris and London, have considered banning diesel engines. Concerns about diesel emissions and threats to ban diesel from many urban areas are projected to cause a plateauing of volumes in the early 2020s as manufacturers shift to more efficient gasoline engines and ramp up new PEV models.

Revenue from Clean Diesel sales declined 12% globally in 2018, to $263 billion, continuing its fall from the 2016 revenue peak of $305 billion. However, U.S. sales of clean diesel vehicles grew from $2.7 billion in 2017 to $3.1 billion in 2018, though revenue was still markedly down from the peak years of 2014-15, when revenue hovered around $6 billion. (Figure 13)

Though the global market is turning away from clean diesel for passenger vehicles, in favor of PEVs, manufacturers still see diesel technology as a path to meeting efficiency targets in certain segments, particularly utility vehicles and pickup trucks. Indeed, growth in the U.S. light commercial and pick-up truck segments

offset losses from German automakers who largely abandoned the U.S. market in 2017.

In 2017, GM and Mazda launched new light-duty diesels trucks and in 2018 Ford added a diesel version of its best-selling vehicle, the F-150 pickup, en route to an announced electric model.

Global and U.S. Clean Diesel Revenue, 2011-18

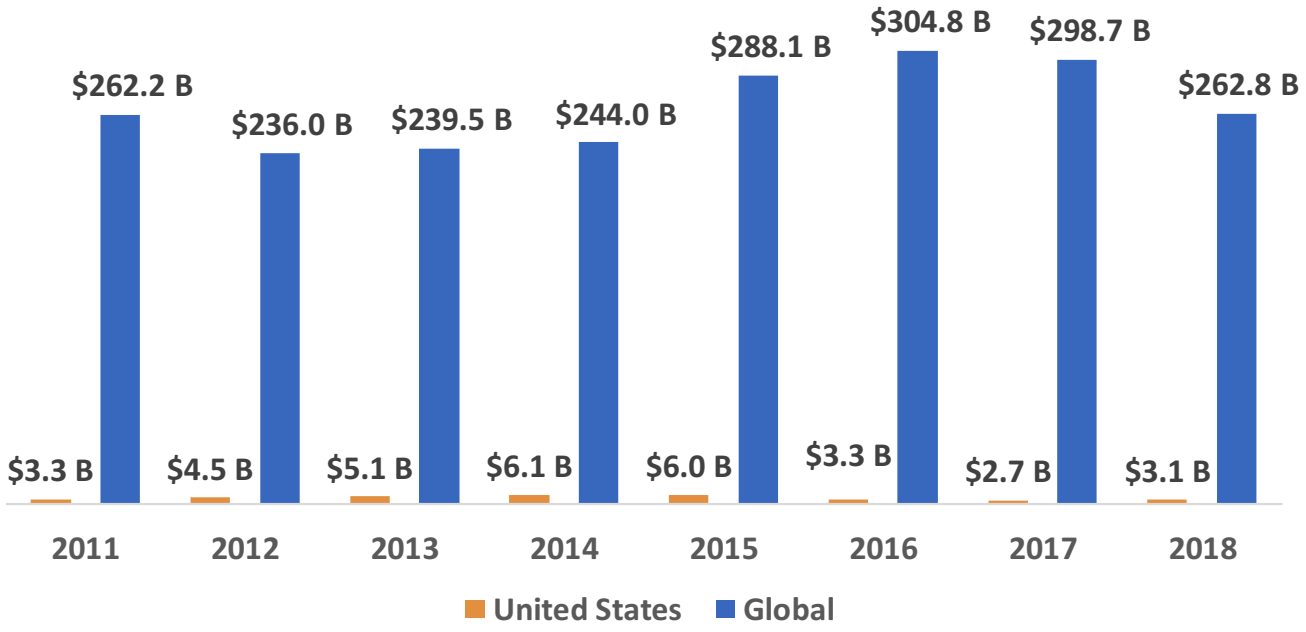

Figure 13 (Navigant Research)

ADVANCED FUEL PRODUCTION

$33.4 BILLION

U.S. revenue

12%

annual growth

$160 BILLION

global revenue

11%

annual growth

Overview

Revenue from Advanced Fuel Production grew to $160 billion worldwide in 2018, an increase of 11%, after bouncing back in 2017 from down years in 2015 and 2016. In the United States, Advanced Fuel revenue staged an even bigger comeback, reaching $33.4 billion in 2018 on 12% growth year over year. In the United States, that growth was led by Ethanol, which had declined sharply in revenue in previous years, and Biodiesel, while globally CNG and LNG used for transportation accounted for the biggest revenue gains over the past two years. The Compound Annual Growth Rate (CAGR) for global Advanced Fuel Production revenue over the 2011-2018 period was 5%, while in

the United States compound annual growth was -4%.

Globally, CNG/LNG revenue grew 6% in 2018 after a 27% jump in 2017, now claiming the biggest share of the Advanced Fuel market since 2015. Biodiesel grew by 27%, reaching its highest level of revenue since we began tracking in 2011. (Table 10) Like CNG/LNG, Ethanol and Butanol fuels had a big year in 2017, registering 17% revenue growth, followed by 7% growth in 2018. Synthetic Diesel and Gasoline and Bio-oil fuels saw the sharpest annual increases in Advanced Fuel Production, both at 39%, though on relatively small bases.

Though still less than 4% of the Advanced Fuels market, Bio-methane grew by 7% globally as landfill gas continues to be captured and is increasingly consumed by waste hauling trucks. Bio-methane for use in transportation is especially growing in the European Union, where efforts to meet the Paris Agreement on climate are prompting investment. According to a study produced by Navigant for the Gas for Climate Consortium, up to 5 billion cubic meters of renewable gas could be sustainably produced in the EU for the transportation sector, which is equal to about 1% of total gas consumption.

Global Fuel Production Revenue (million $)

Subsegment	2011	2012	2013	2014	2015	2016	2017	2018 estimate
CNG and LNG	23,018	31,486	37,654	43,302	52,439	57,420	72,924	77,299
Ethanol and Butanol	68,140	84,240	76,645	77,956	46,218	36,964	43,248	46,275
Bio-diesel	17,882	20,432	21,993	21,342	19,692	19,998	23,998	30,477
Synthetic Diesel and Gasoline	1,580	1,938	4,693	5,394	3,142	3,207	3,849	5,350
Bio-oil	1	500	805	16	19	0	0	0
Bio-methane	47	48	65	51	416	496	615	656
Hydrogen	-	-	-	-	-	-	-	-
Total	110,667	138,644	141,855	148,062	121,926	118,086	144,635	160,059

Table 10 (Navigant Research)

U.S. Fuels Revenue Rebounds

In the United States, revenue from Advanced Fuel Production increased 12% overall, its second year of growth following two years of sharp decline. Biodiesel revenue rose sharply (43%) in 2018, buoyed by the $1 per gallon biodiesel tax credit retroactively

extended for 2017 by Congress in February 2018, with revenue realized in 2018. Biodiesel production was up 16% in 2018, possibly with the expectation that the tax credit will be renewed again. The average retail price of biodiesel increased by 11% in 2018, which also contributed to the higher overall revenue.

Also, in January and April 2018, the U.S. Commerce Department imposed antidumping and countervailing duty orders on biodiesel after finding "that an industry in the United States is materially injured by reason of imports of biodiesel from Argentina and Indonesia." However, in November, the government said that it was undertaking a "changed circumstances review" of the duty orders, which could undo the prior actions and impact the price and sales of U.S.-produced biodiesel going forward.

Ethanol and Butanol revenue grew by 11%, to $22.4 billion, comprising the largest share of the U.S. Advanced Fuel Production market. (Table 11) Declining revenue from Ethanol had been a drag on this segment as a whole in 2015 and 2016. Since then, the price steadied, and in 2018 posted a slight increase, contributing to the upturn last year.

Market growth outpaced the production requirements mandated by the EPA's Renewable Fuels Standards, which had a smaller target for cellulosic ethanol, and essentially flat targets for advanced and renewable biofuels. (Table 12)

Though only domestic consumption is counted in the U.S. revenue (Table 11), exports reached a record 1.7 billion gallons in 2018. Nearly 11% of U.S. ethanol was exported, with total exports exceeding 2017 levels by 25%. Significant blending mandates in India, Australia, China, and Philippines helped drive demand for ethanol globally.

U.S. Advanced Fuel Production Revenue (million $)

Subsegment	2011	2012	2013	2014	2015	2016	2017	2018 estimate
CNG and LNG	504	581	883	1,016	1,271	1,288	1,674	1,574
Ethanol and Butanol	39,140	41,730	40,371	40,932	27,331	20,580	20,190	22,386
Bio-diesel	3,135	4,231	4,751	3,859	3,200	4,567	5,074	7,256
Synthetic Diesel and Gasoline	372	438	2,368	3,206	3,564	2,100	2,352	1,717
Bio-oil	1	345	2	16	0	-	-	-
Bio-methane	12	12	16	19	341	410	441	491
Hydrogen	-	-	-	-	-	-	-	-
Total	43,164	47,337	48,390	49,048	35,708	28,944	29,731	33,424

Table 11 (Navigant Research)

Despite growing globally, CNG/LNG revenue fell by 6% in the United States last year after 30% growth in 2017. At just $1.6 billion in 2018, this fuel commands a much smaller share of the U.S. Advanced Fuels market than it does globally, as it is currently used primarily in transit buses and waste-hauling trucks. Synthetic Diesel and Gasoline revenue also fell by 27%, to $1.7 billion, in 2018. **But Bio-methane revenue grew 11% over 2017. Since 2011, the U.S. market for this fuel from landfills and anaerobic digesters has grown at a compound annual rate of 78%, by far the fastest growth of any Advanced Fuel subsegment over this period.**

EPA Renewable Fuel Volumes (billion gallons)

Fuel Type	2011	2015	2016	2017	2018	2019	2020
Cellulosic	0.03	0.12	0.23	0.31	.29	.42	n/a
Synthetic Diesel and Gasoline	1.63	1.73	1.9	2.0	2.1	2.1	2.43
Biodiesel	2.67	2.88	3.61	4.28	4.29	4.92	n/a
Ethanol and Butanol	16.28	16.93	18.11	19.28	19.29	19.92	n/a
Cellulosic	0.03	0.12	0.23	0.31	.29	.42	n/a

Table 12 – Units for all volumes are ethanol-equivalent, except for biodiesel volumes, which are expressed as physical gallons. Source: EPA.

Trucks and Ports Boost LNG and Bio-Methane

In many places around the world, truck fleets are moving to LNG as a way to reduce costs and emissions, accounting in part for the strong growth of CNG/LNG fuel worldwide (though less in the United States). Scania of Sweden has delivered LNG trucks to Italy, Argentina, and Spain. The company has also introduced natural gas buses in the UK. Also adding to the demand for LNG in road transport are Volvo trucks, which are being sold in Ireland, Switzerland and the UK.

Ports are increasingly leveraging LNG fuel depots for both seafaring vessels and local trucks. For example, at the Wilhelmshaven Floating Storage and Regasification Unit in Germany, the LNG terminal will be expanded to include infrastructure to accommodate ships, barges, and ground transport. Similarly, pipelines will bring LNG to Port Arthur, Texas, where it will be used for both land and sea vessels. The Port of Antwerp is undertaking a similar upgrade.

Also, on the rise is the use of bio-methane, sometimes called renewable natural gas, for transportation purposes, especially in Europe. Scania, Shell, Nordsol and others have partnered on the BioLNG EuroNet initiative, which is receiving funding from the European Union. The group will launch 39 fueling

stations using organic industrial waste and deploy 2,000 heavy-duty LNG trucks in six countries across Western and Northern Europe. Bio-methane is also starting to gain traction in the United States. The town of Longmont, Colorado, is converting 11 of its 16 diesel trash trucks to use renewable natural gas, and the Ports of Long Beach and Los Angeles are set to begin using bio-methane for their fleet operations.

Hydrogen Makes Some Headway

Hydrogen fuel revenue continues to register zero worldwide, despite big plans by automakers and certain national and, in the United States, state governments to ramp up this alternative. The current price of Hydrogen fuel equates to a cost of nearly $15 per diesel gallon equivalent. However, the cost to drive per mile is much closer as fuel cell vehicles are about twice as efficient as comparable internal combustion engine (ICE) vehicles. Driving the prohibitive cost of hydrogen is the small scale of deployment as well as the technological requirements for producing, storing, and conveying hydrogen. Hydrogen refueling stations in the US are limited to (largely coastal) California, which opened its 39th hydrogen refueling station. The state has a goal of operating 100 hydrogen fueling stations by 2024.

Approximately 2,300 fuel cell passenger vehicles were sold in California in 2018, with three models available – the Toyota Mirai, Honda Clarity Fuel Cell, and the Hyundai NEXO. This brings the total number of fuel cell cars in operation to more than 5,000. In July 2018, California stated an ambitious goal of getting one million fuel cell vehicles on its roads by 2030. The government of South Korea continues to back hydrogen as a fuel and announced its intention to build 1,200 refueling stations by 2040 and produce millions of fuel cell cars. China and Japan each have established goals to install 1,000 hydrogen refueling stations in the coming decades.

Interest in hydrogen as a fuel for large trucks and buses derives from advantages in driving range and weight when compared to battery electric vehicles. California is piloting 25 fuel cell buses with another 31 buses and shuttles in development. Toyota and PACCAR are currently testing two heavy-duty fuel cell trucks at ports in Southern California, and they are collaborating on developing another 10 vehicles. Startup truck manufacturer Nikola intends on testing its fuel cell trucks by the end of 2019, the company said it would develop up to 700 hydrogen fueling stations during the next seven years. In Switzerland, Hyundai will work with partner H2 Energy to deliver up to 1,000 fuel cell trucks by 2023. In Europe, the expansion of solar and wind production is increasing interest in using electrolysis to produce renewable hydrogen for use in transportation. As highlighted by the World Economic Forum, France, the Netherlands and Norway are moving forward with renewable hydrogen initiatives.

ADVANCED INDUSTRY

$9 BILLION

U.S. revenue

0%

annual growth

$54.5 BILLION

global revenue

12%

annual growth

Overview

Advanced Industry, the sixth largest advanced energy segment both globally and domestically, contains two subsegments: Manufacturing Machinery and Process Equipment and Industrial Combined Heat and Power (CHP). (For non-industrial applications of CHP, see Building Efficiency).

Manufacturing Machinery and Process Equipment is tracked through sales of industrial energy management systems, which are software and services for energy management within an industrial facility or across an enterprise to meet efficiency, cost savings, and sustainability targets while

maintaining optimal operation of production processes.

Global Advanced Industry revenue reached $54.5 billion in 2018, a 12% increase over 2017, building on 11% growth the year before. (Table 13) This is an acceleration over previous years of steady growth driven by the expansion of manufacturing machinery and process equipment caused by increased global production and the adoption of advanced technology in industrial processes. Compound Annual Growth Rate (CAGR) for global Advanced Industry revenue over the 2011-18 period was 9%. Growth in U.S. revenue was even greater over the period since 2011, more than doubling in that time, with CAGR of 12%, but essentially flat in 2018.

Global Advanced Industry Revenue (million $)

Subsegment	2011	2012	2013	2014	2015	2016	2017	2018 estimate
Manufacturing Machinery & Process Equipment	9,773	10,513	11,340	12,315	13,465	14,809	18,219	21,628
Combined Heat & Power	20,803	22,812	27,155	28,513	29,938	29,116	30,603	32,859
Total	30,576	33,325	38,495	40,828	43,403	43,925	48,821	54,487

Table 13 (Navigant Research)

In the United States, the Advanced Industry segment plateaued in 2017 and 2018, driven by a contraction in CHP sales amid a deceleration in overall industrial expenditure.

While CHP is the dominant subsegment globally, Manufacturing Machinery and Process Equipment is the larger of the two in the United States.

U.S. Advanced Industry Revenue (million $)

Subsegment	2011	2012	2013	2014	2015	2016	2017	2018 estimate
Manufacturing Machinery and Process Equipment	3,184	3,414	3,669	3,969	4,325	4,744	5,162	5,308
CHP	1,018	2,038	3,064	3,217	3,378	3,540	3,920	3,735
Total	4,202	5,452	6,733	7,186	7,703	8,283	9,082	9,044

Table 14 (Navigant Research)

In 2018, U.S. Manufacturing Machinery and Process Equipment revenue increased 3% to $5.3 billion based on sales of industrial energy management systems. (Table 14) CHP revenue declined by 5% year-over-year to $3.7 billion, following 11% growth in 2017. Since 2011, U.S. Advanced Industry revenue has grown at an impressive compound annual rate of 12%.

From Industrial Energy Management Systems to Industrial Internet of Things

Executives in charge of industrial facilities are becoming more aware of the benefits of data and automation as a source of opportunity for business improvement. As the costs of sensors and devices continues to decline, a vibrant market of industrial internet of things (Industrial IoT) is building on the growth of industrial energy management systems. In simple terms, Industrial IoT is the use of digital and internet technologies and tools—e.g., hardware, software, and analytics—for the benefit of business processes.

Industrial IoT enables more efficient use of energy as equipment makes intelligent adjustments to energy consumption and lowers operational costs through the enhanced predictive and preventive maintenance. However, this emerging trend differs from traditional energy management systems in that its focus is far broader than energy. IIoT systems are becoming the go-to solution for leveraging data to deliver economic and business benefits.

The IIoT represents a transformative set of digital tools that managers can employ to improve efficiency throughout operations. While achieving greater efficiency is an overarching force in the marketplace, multiple drivers fuel the IIoT trend. Here is a sampling:

- **More efficient use of energy:** Equipment that senses how it is operating in terms of energy use and makes intelligent adjustments (e.g., slowing down or turning off when rates are high) is inherently more energy efficient, leading to lower energy costs.
- **Predictive, preventive maintenance:** Industrial machinery can last longer with sensors that continually monitor conditions and report when maintenance is necessary ahead of scheduled service, or delay work that is unneeded, thus lowering costs. For instance, a grocery store with an IoT system could receive alerts and accurate diagnostics hours or days in advance of when a specific chiller is about to fail, thus triggering precise maintenance work and preventing costly downtime and spoiled products.
- **Competitive differentiation:** As leading companies deploy IIoT solutions and gain efficiencies, they can offer products and services at lower costs, thus separating themselves from competitors. Customers want to work with companies that learn from and master IIoT technologies.
- **Transforming businesses:** Firms that deploy IIoT solutions can transform their business, offering customers enhanced services, and more efficient, reliable operations. For example, Schindler Ahead, a digital solution that

elevator manufacturer Schindler calls its Internet of Elevator and Escalator strategy, provides real-time equipment status, operational metrics, and personalized services for improved passenger experiences.

Navigant Research expects global annual revenue for IIoT devices, software, and services to grow from $1.6 billion in 2018 to $7.5 billion in 2027, at a compound annual growth rate (CAGR) of 19%. (Figure 14)

Over the next 10 years, early adopting companies will pave the way for others to follow and reap the benefits this technology offers: greater efficiencies, lower costs, and higher margins. Cumulatively, this revenue is expected to total more than $35 billion between 2019 and 2027.

Industrial IoT Device, Software, and Service Revenue for Manufacturing, Global, 2018-2027

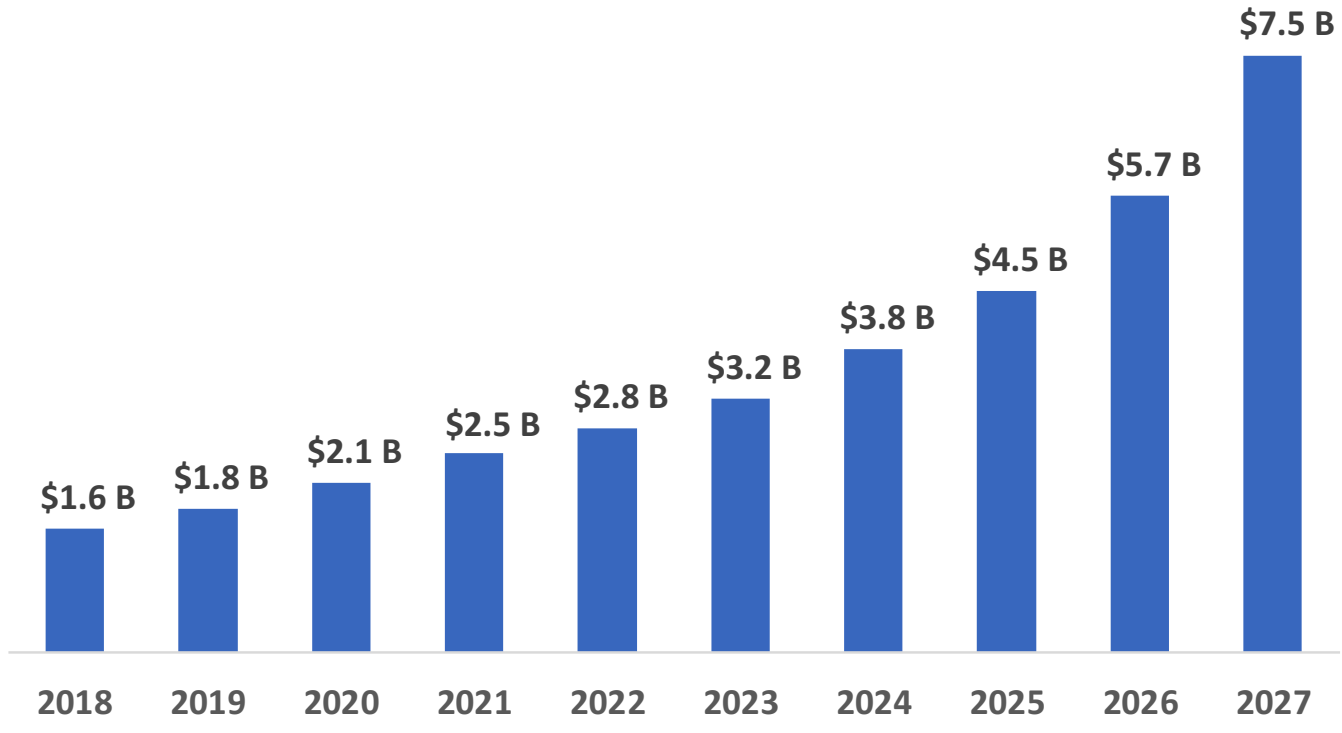

Figure 14 (Navigant Research)

ADVANCED FUEL DELIVERY

$168 MILLION

U.S. revenue

5%

annual growth

$991 MILLION

global revenue

0%

annual growth

Overview

Advanced Fuel Delivery revenue – here quantified for just Fueling Stations serving natural gas and hydrogen vehicles – remained essentially flat globally in 2018, at $991 million, after 4% increase in 2017. (For Charging Infrastructure for electric vehicles, see Electricity Distribution and Management.) **In the United States, the market for Advanced Fuel Delivery grew 5% in 2018, after three years of declines.** Overall, spending on natural gas and hydrogen fueling stations has shrunk by more than half worldwide since 2011, and by one quarter in the United States, and by even more compared with the peak years of 2014 and 2012, respectively. The Compound Annual

Growth Rate (CAGR) for Advanced Fuel Delivery revenue was -11% from 2011 to 2018 globally and -4% in the United States.

Investments in natural gas refueling equipment for larger vehicles dropped 36% last year worldwide, perhaps influenced by increasing interest in the electrification of medium- and heavy-duty trucks. Natural gas infrastructure for light duty vehicles, which accounts for the bulk of revenue in this segment, increased 2% to $920 million. Hydrogen fueling station revenue grew by $1 million to $33 million.

Global Fuel Delivery Revenue (million $)

Subsegment	2011	2012	2013	2014	2015	2016	2017	2018 estimate
Fueling Stations	2,207	1,926	2,606	2,718	900	953	993	991
Fuel Transportation Infrastructure	-	-	-	-	-	-	-	-
Total	2,207	1,926	2,606	2,718	900	953	993	991

Table 15 (Navigant Research)

In the United States, spending on Fueling Stations rose 5% in 2018 to $168 million. This was due to higher spending on light-duty natural gas fueling – surprising, given that there are currently no light duty vehicles available for purchase. CNG vehicles continue to be driven in the United States, with CNG models for the Honda Civic and Chevrolet Impala, which GM stopped producing in 2016. Commercial natural gas fueling infrastructure, for larger vehicles, dropped by nearly a third in 2018 to $27 million, even farther from a peak of nearly $100 million in 2014, even though the commercial price per thousand cubic feet fell to $7.36 late in the year, according to the Energy Information Administration.

U.S. Fuel Delivery Revenue (million $)

Subsegment	2011	2012	2013	2014	2015	2016	2017	2018 estimate
Fueling Stations	227	378	252	283	186	178	160	168
Fuel Transportation Infrastructure	-	-	-	-	-	-	-	-
Total	227	378	252	283	186	178	160	168

Table 16 (Navigant Research)

Despite growing interest in hydrogen as a fuel for passenger cars and heavy-duty vehicles, investment in hydrogen fueling stations dropped from $8 million in 2017 to just $5 million. This falloff is likely short term, as investment in hydrogen refueling is expected to increase in the coming years, especially in California.

Natural Gas Fueling Stations Follow Fleet Growth

Outside of North America, natural gas as a fuel for passenger cars continues to grow, along with fueling stations, with revenue of $920 million globally in 2018. (Figure 15) The ECO-GATE (European COrridors for natural GAs Transport Efficiency) consortium, which was established in 2017, is propagating natural gas fueling stations. In June 2018, the European Union approved €10 million for an ECO-GATE project to develop and implement 21 gas stations that will be installed in Spain, France, Portugal and Germany. The program developers tout a significant reduction in the unit cost of new fueling stations.

In 2019, a new branding scheme for natural gas fueling stations was announced. Co-financed by the European Union and led by NEDGIA (Naturgy Group's gas distributor), the ECO-G brand was designed to convey "smart ecology" for its environmental benefits and cost savings when compared to diesel. The ECO-G brand will be standardized across natural gas fueling stations for light, medium, and heavy-duty vehicles, as well as maritime refueling.

The new fueling stations are welcome news as more CNG car models are re-entering the market in Europe. Volkswagen is reintroducing the Polo and Golf TGI vehicles with increased driving range. Automaker Seat, which uses the same vehicle platform as the Polo and Golf, is bringing three refreshed CNG vehicles to market: the Ibiza, Arona, and Leon.

Global Natural Gas Vehicle Fueling Stations Revenue (millions)

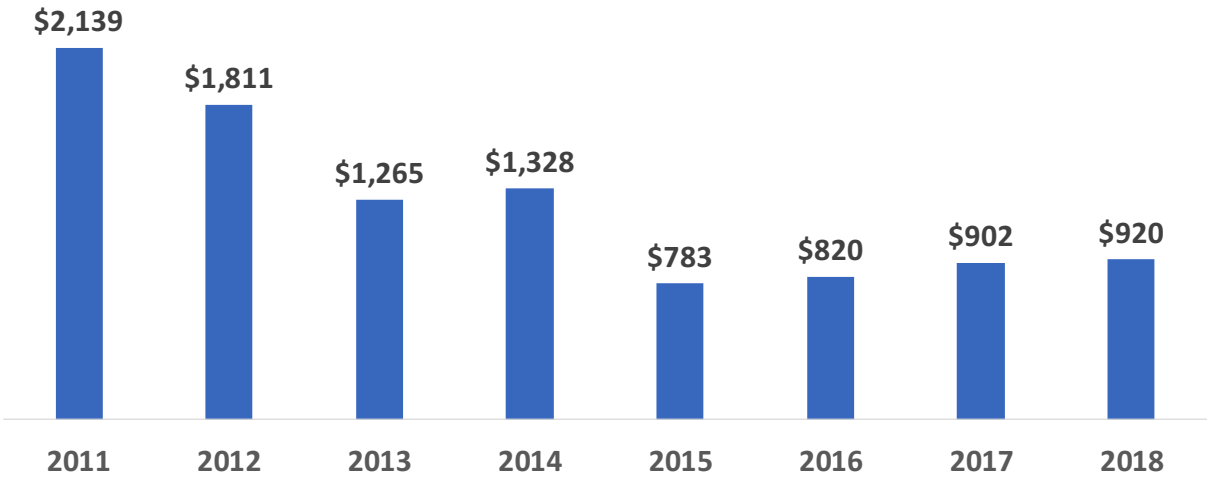

Figure 15 (Navigant Research)

Italy has more than 1 million natural gas vehicles and more than 1,100 fueling stations. The Lombardy region is incentivizing drivers to purchase a new natural gas vehicle, offering a three-year abatement on the regional automotive ownership tax if a polluting vehicle is also exchanged, or a 50% reduction in the tax for new vehicle purchases.

Further east, in India, the government established a dealer-owned and operated model for CNG stations across the country. More than 1,500 CNG stations are presently operational in the country, with more than 4,600 new CNG stations expected in the next eight years. The gas pipeline infrastructure is expected to be nearly doubled during this time.

In Brazil, transportation network company Uber is encouraging drivers to convert their vehicles to CNG. Through a partnership with Landi Renzo Group, Uber drivers can get access to low-interest financing for Landi Renzo's natural gas conversion kits.

U.S. Natural Gas Vehicle Fueling Stations (millions)

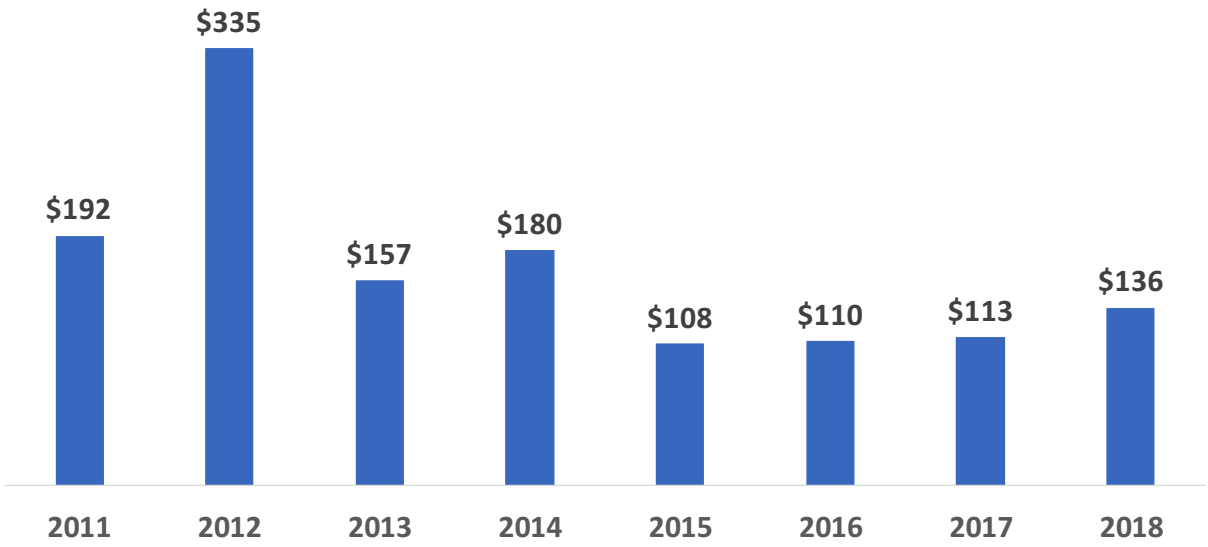

Figure 16 (Navigant Research)

In the United States, CNG continues to be pursued alongside electrification as a viable option for transit buses, if not for light duty vehicles, resulting in Fueling Station revenue of $136 million in 2018. (Figure 16) For example, the Santa Clarita, CA, bus fleet is now more than 90% CNG vehicles, and the fleet will soon move to 100% CNG. Bio-methane digesters will increase the fuel supply to natural gas pipelines in California. A pilot project will connect six locations in central California with pipelines to demonstrate how waste from dairy farms can augment existing natural gas supplies. Similarly, waste

management company CR&R Environmental is feeding bio-methane into pipelines operated by SoCalGas.

In Lebanon, PA, outside of Harrisburg, 29 CNG fueling stations are being installed to provide infrastructure for the fleet of buses, which is expected to reach 1,600. The infrastructure is provided through a $84.5 million public private partnership between the Pennsylvania Department of Transportation and natural gas fuel supplier Trillium.

Global Efforts Are Driving Hydrogen Fuel Stations

Automotive and transportation companies are divided over hydrogen fuel cells versus batteries for long range electrified driving. While hydrogen fueling infrastructure has existed for decades, growth has been much slower than electric vehicle (EV) charging infrastructure. Global hydrogen fueling infrastructure revenue is 32% lower in 2018 than it was in 2011. However, a resurgence of interest in hydrogen, particularly for trucking, could lead to stronger investment in the coming years.

The Chinese government, which has focused primarily on incentivizing EVs as part of its New Energy Vehicle plan, is now promoting hydrogen as well. Wan Gang, a senior government advisor who was instrumental in the country's EV strategy, wrote in December that the country should now focus on hydrogen fuel cell vehicle development. In 2018, Chinese light truck manufacturer Great Wall joined the International Hydrogen Council and established a hydrogen research and development center. The company also invested in H2 Mobility Deutschland, a German hydrogen refueling company, as well as Shanghai Fuel Cell Powertrain Co. The first commercial-scale liquid hydrogen fueling station in China is being developed in Guangdong Province, using technology from Pennsylvania-based company Air Products.

Automakers in Korea and Japan are continuing to support hydrogen infrastructure and fuel cell vehicles. In Japan, 80 new hydrogen refueling stations are planned to be built through 2022 by a consortium of companies including automakers Honda, Nissan, and Toyota. Meanwhile, Korea's Hyundai plans on spending $6.7 billion through 2030 to increase hydrogen vehicle production. Hyundai is launching its Nexo fuel cell vehicle and a fleet of heavy-duty trucks in Europe in 2019, which will require new investment in hydrogen refueling infrastructure.

In Europe, a new hydrogen refueling station in Wuppertal, Germany, will power a fleet of fuel cell buses. Hydrogenics Corp. will build the system to extract hydrogen from water via electrolysis. Hydrogenics is also part of the Haeolus consortium, which is building a 2.5 MW electrolyzer-based hydrogen production facility in Norway. When complete, the facility will be directly connected to a 45 MW wind farm to turn excess renewable energy into hydrogen fuel.

These global efforts to expand hydrogen infrastructure will further refine the production process and narrow the cost gap between hydrogen fuel and other transportation fuels.

ADVANCED ELECTRICITY GENERATION

$59.6 BILLION

U.S. revenue

8%

annual growth

$453 BILLION

global revenue

0%

annual growth

Overview

Advanced Electricity Generation is now the second largest advanced energy segment globally, having been displaced as the biggest by Advanced Transportation in 2017. **At $453 billion, Advanced Electricity Generation was down slightly in 2018.** Global revenue has been largely flat for the past two years, dropping roughly $1 billion each year since 2016, but the total masks significant growth in solar and hydropower in 2017, nuclear power in 2018, and wind in both years. In the United States, Advanced Electricity Generation continues to be the second largest segment of the advanced energy market and is still growing strongly, up 8% in 2018, with revenue growth in wind and solar, while natural gas

turbines held steady. **Over the 2011-18 period, the compound annual growth rate (CAGR) for Advanced Electricity Generation revenue was -1% globally, while for U.S. revenue compound annual growth was 6%.**

Advanced Electricity Generation in 2018 globally was boosted by investment in nuclear generation. Meanwhile, large hydropower projects in Africa continue to materialize, despite long development cycles, and hydro buildout in Asia continues. Hydro led all generation categories with $122.6 billion in revenue in 2018. Though now accounting for more than 1,300 GW of installed capacity worldwide, Hydro revenue declined 13% from 2017 to 2018. Solar PV, at $119.3 billion, declined 16% over 2017 after three consecutive years of revenue growth. This is primarily a function of declining prices, as 5.4 GW of Solar PV was installed in 2018, up slightly from 5.3 GW in 2017. (Table 17)

Global Advanced Electricity Generation Revenue (million $)

Subsegment	2011	2012	2013	2014	2015	2016	2017	2018 estimate
Solar	96,193	87,672	96,828	94,800	99,057	132,084	142,297	120,132
Wind	67,069	82,111	67,685	94,575	103,273	86,368	93,781	95,361
Geothermal	666	1,730	1,470	1,500	1,700	2,148	1,033	1,094
Hydro	185,260	149,098	84,328	133,871	143,650	97,311	140,780	122,587
Marine	300	140	-	-	-	-	0	0
Waste	4,700	2,750	5,910	2,954	3,223	1,497	2,815	3,030
Biomass	10,500	7,200	14,700	13,500	5,900	8,500	9,214	9,244
Nuclear	40,805	34,210	14,300	15,950	18,068	79,844	19,648	60,582
Gas Turbines	55,481	42,755	42,043	40,199	46,667	37,534	33,046	28,278
Fuel Cells and Other DG	755	1,009	6,618	7,079	10,927	10,297	11,603	12,679
Total	**461,729**	**408,674**	**333,882**	**404,428**	**432,464**	**455,582**	**454,218**	**452,987**

Table 17 (Navigant Research)

Growth in Wind revenue, the third largest generation category globally, has been somewhat cyclical, partly due to fluctuations in the United States tied to the federal production tax credit (PTC). In 2018, Wind revenue grew 2%, to $95 billion globally. But there has been far greater year-to-year variability in Nuclear, and 2018 was a big up year. With an estimated $60 billion in new orders, Nuclear saw an increase of 208% after a 75% drop in 2017, following a record

number of projects in 2016. Most of this growth occurred in Asia, led by China.

Gas turbine markets, including simple cycle and combined cycle varieties, declined 14% to $28 billion in revenue in 2018, the lowest total for new orders in the eight-year period covered in this report.

In the United States, Advanced Electricity Generation remained the second largest advanced energy segment, with $59.6 billion in revenue in 2018. Growth in this segment over 2017 was 8%, slightly higher than compound annual growth of 6% from 2011 to 2018.

U.S. Advanced Electricity Generation Revenue (million $)

Subsegment	2011	2012	2013	2014	2015	2016	2017	2018 estimate
Solar	8,246	11,850	19,519	22,110	19,188	24,945	23,969	25,562
Wind	12,993	25,461	2,060	8,252	14,450	14,064	11,417	13,993
Geothermal	118	723	833	450	450	629	489	910
Hydro	-	386	-	897	488	179	739	531
Marine	30	-	-	-	-	-	0	0
Waste	640	290	550	348	524	227	142	54
Biomass	300	600	900	882	-	22	424	352
Nuclear	12,287	-	-	-	-	-	0	0
Gas Turbines	4,017	4,542	4,376	9,204	10,455	9,208	15,088	15,076
Fuel Cells and Other DG	182	91	2,165	2,394	2,725	2,913	3,019	3,123
Total	38,813	43,943	30,404	44,537	48,280	52,187	55,288	59,601

Table 18 (Navigant Research)

For the seventh year, renewable energy accounted for the most new utility-scale capacity, with nearly 11 GW added in 2018. **At $24.2 billion, Solar PV remained the largest product category, showing an 8% increase in revenue even as costs declined.** Including distributed as well as utility-scale, Solar PV totaled 13.4 GW installed in 2018, up 14% from 11.8 GW in 2017. $1.3 billion in Solar Thermal brings total Solar revenue to a high of $25.6 billion. (Table 18)

Wind remained the second largest subsegment, with $13.9 billion in revenue, up 23% after a down year in 2017. Looking over the past four years, U.S. wind revenue seems to be settling in at roughly $14 billion annually under the five-year extension and phase-out of the federal Production Tax Credit, in marked contrast to boom-and-bust cycles of previous years when fate of the PTC was uncertain.

U.S. revenue for Gas Turbines was $15.1 billion, unchanged from 2017, but up 64% over 2016.

Despite little activity in 2015 and 2016, Biomass recovered a bit in 2017 and 2018, reaching $352 million in 2018. Geothermal (up 86%) experienced strong year-on-year growth, with $910 million in revenue. Meanwhile, Fuel Cells and Other Distributed Generation was up 3% to $3.1 billion, while Waste was down 62% at $54 million.

U.S. Solar PV, Wind, and Gas Turbine Revenue

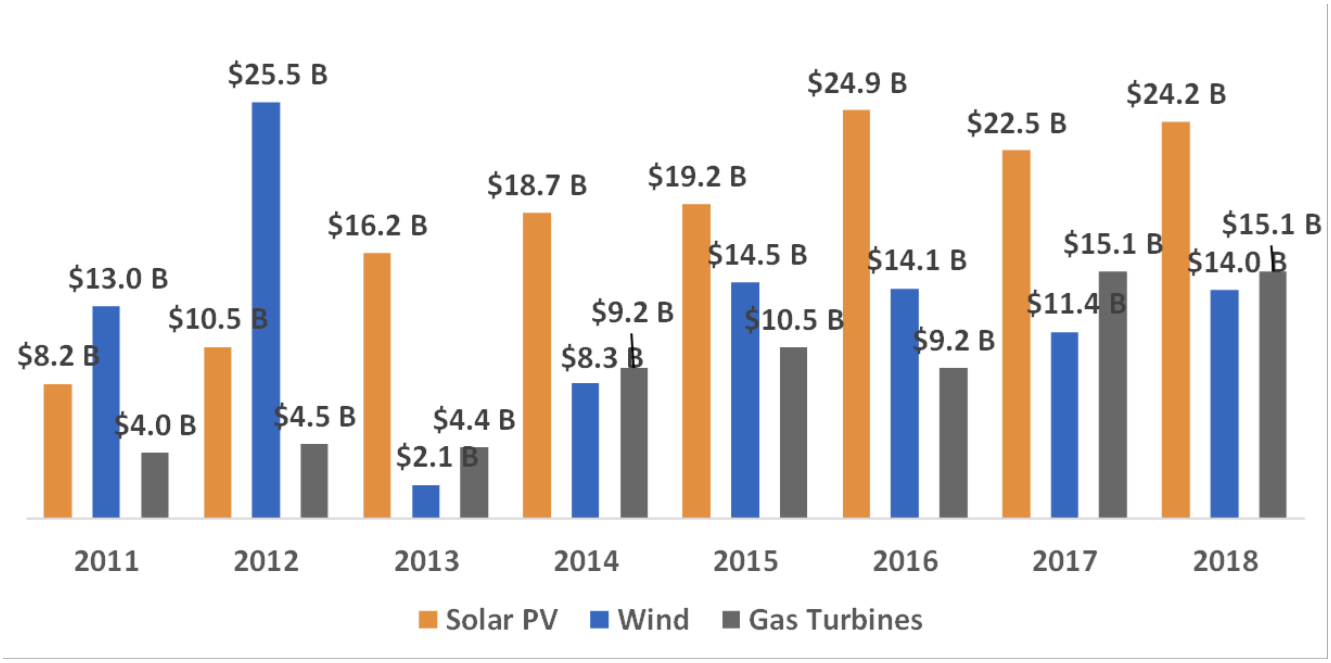

Figure 17 (Navigant Research)

Solar, Wind, Natural Gas Ramp Up as Coal Retires

In the United States, continued coal retirements are driving greater use of existing natural gas facilities, new combined cycle generation, and renewable energy, with revenue flowing accordingly. (Figure 17) Look for solar and wind to be paired with storage and begin to compete more directly with natural gas in many markets. Many states are increasing their Renewable Portfolio Standards and considering similar policies to achieve 100% clean grids, with Hawaii and California already setting 100% renewable or clean energy commitments, while several newly elected governors have voiced intention to set similar goals.

U.S. Wind and Solar markets continue to be the largest sources of revenue in this segment, with Solar PV slightly lower in 2017 following a massive 2016. In 2018, Solar PV revenue rebounded to $24.2 billion – nearly matching

the 2016 peak of $24.9 billion – driven primarily by utility-scale installations.

Solar PV's steady growth benefits from extension of the federal Investment Tax Credit at the 30% level through 2019, after which it ratchets down for large installations (and phases out entirely for residential), along with falling prices, which are projected to continue. (Figure 18)

With revenue of $14 billion three of the past four years, the Wind industry seems to have lost its boom-and-bust character, at least through the extension and phase-out of the Production Tax Credit this year.

The use of natural gas in power generation is expected to increase, although with potentially not as many new builds, as utilities find solar, wind, storage, and demand management competitive in meeting their capacity needs. This is evidenced by Northern Indiana Public Service Co.'s plan to replace all its remaining coal plants with these resources.

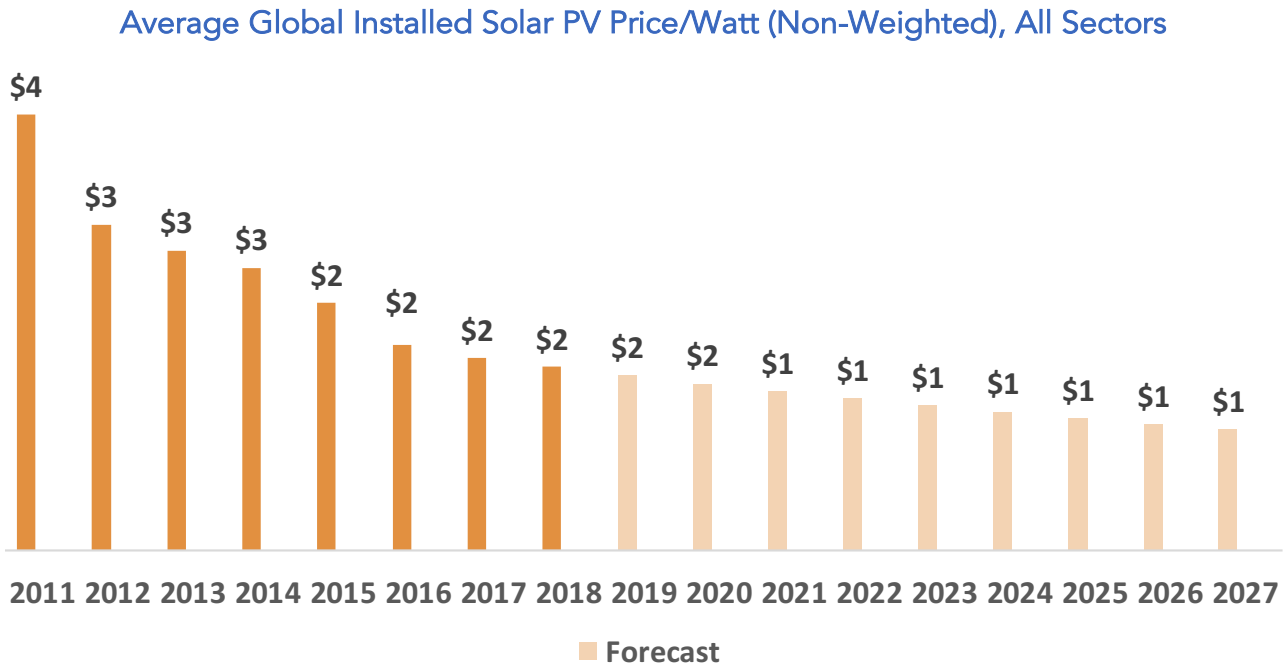

Figure 18 (Navigant Research)

Utilities will be examining the locational value of distributed energy resources, (DER) particularly in states like California and New York. Navigant expects continued growth in DER deployment, with annual global capacity additions increasing four-fold by 2026. Energy storage integration will continue at both utility-scale and distributed renewables.

U.S. offshore wind markets are also ramping up, with large procurements announced in New York and New Jersey, following Massachusetts, Rhode Island, and Connecticut. Several thousand MW of offshore wind are expected to be developed along the eastern seaboard, and results from Massachusetts suggest pricing will be lower than expected.