



# Solid oxide fuel cells

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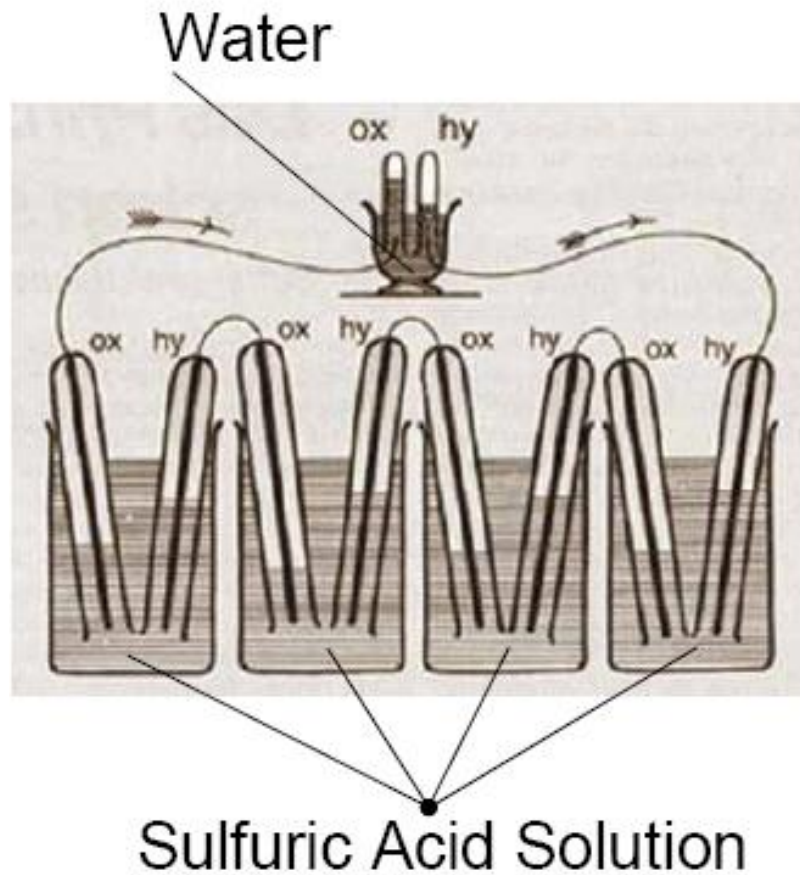
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- Short history
- Example on Niche markets
  - ENE-FARM (Japan)
  - Bloom Energy (USA)
- Some numbers

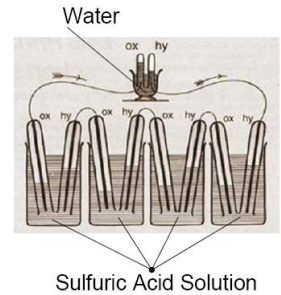


# Fuel Cell of William Grove (1839)

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# Fuel Cell of William Grove (1839)



- "*Gaseous voltaic battery*"
- Two platinum electrodes were halfway submerged into beakers of sulphuric acid
- Inverted tubes over the electrodes
  - One with hydrogen
  - One with oxygen
- Galvanometer indicated a flow of electrons between the electrodes
- Published in "*Philosophical Magazine and Journal of Science*"

# Introduction to fuel cells

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- Fuel is directly converted to electrical energy, with water/heat as by-products
  - No Carnot cycle limitation
  - Environmental friendly
- The principle dates back to 1838/39
- Fuel cells are expected to be a key component in a future sustainable energy system
- Strategic niche markets will be important for commercialization



# Introduction to fuel cells

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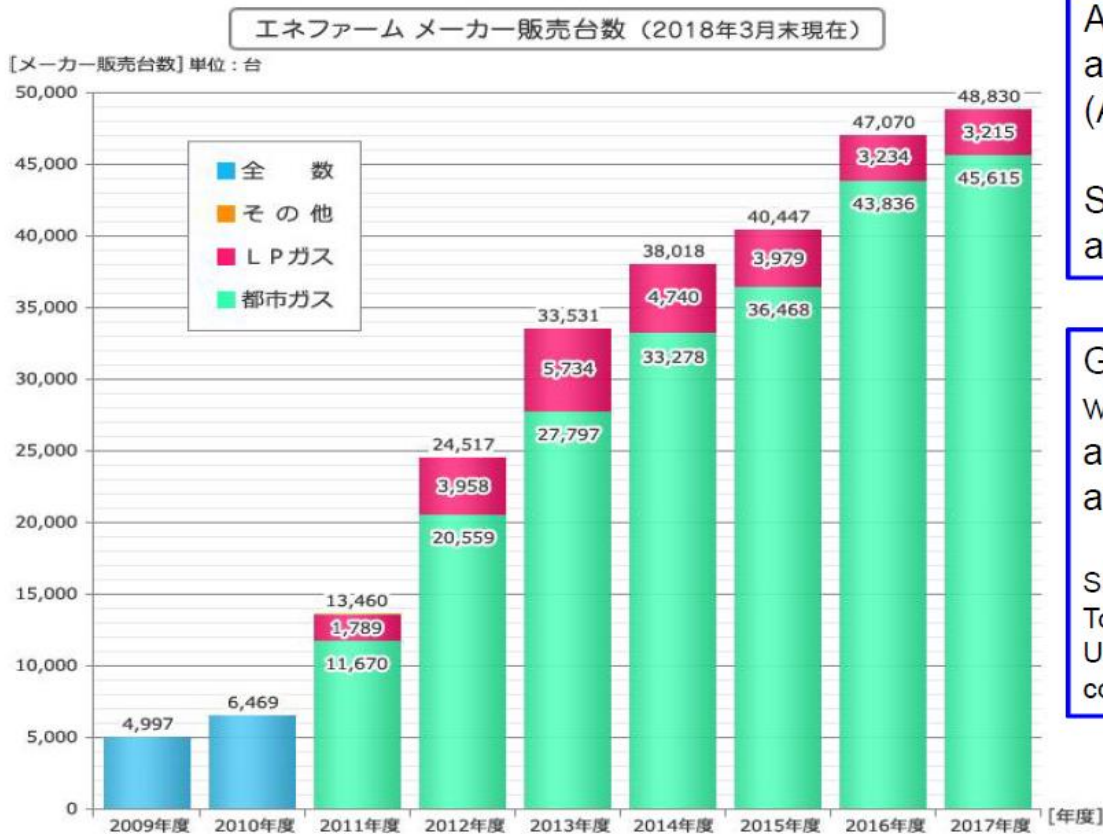
- ... in 5 years the fuel cells will ...
- Life length (durability)
- Cost
- No fuel available...





# Japan – ENEFARM (700W) -status 2018

## Number of Sales for Ene-farm system



Accumulated number:  
above 250,000 units  
(April 2018)

SOFC system:  
above 30,000 units

Governmental subsidy  
will end:  
at 2019 for PEM  
at 2021 for SOFC

Subsidy: 1,000-3,000 USD  
Total price: 11,000 -14,000  
USD including construction  
cost

Source from Co-generation Foundation Japan: [https://www.ace.or.jp/fc/works\\_0010.html](https://www.ace.or.jp/fc/works_0010.html)



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# Japan – ENEFARM (700W) -status 2018

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Governmental (METI) policy from 2017

- Objective: To subsidy ENEFARM as well as FCs for business/industry
- Targets
  - 1 400 000 units of ENEFOFAM installed in 2020
    - Price of PEFC system 800 000 Yen in 2019
    - Price of SOFC system 1 000 000 Yen in 2010
  - Business / Industrial use
    - System cost of 500 000 Yen/kW in 2020
- Subsidy
  - ENEFARM = fixed amount (decreases on annual basis)
  - Business / Industrial = Initial 1/3





# Japan – going from 700 W to 3KW

## -status 2018

### Business Use 3kW System

Kyocera 3 kW system have been commercialized with Ene-farm technology  
More than 10 units have been installed in the shops, restaurants, etc.



Power generation unit

#### Specifications

Rated Output of Power Generation (AC)	3kW
Rated Power Generation Efficiency	52.0% (LHV, default)
Rated Overall Efficiency	90% (LHV, default)
Dimensions	1,150 W × 675 D × 1,690 H (mm)
Weight	375 kg
Gas type	City gas (13A)

\* A hot water storage unit (200L) separately sold by Noritz Corporation is also required.

Data from:

[https://www.kyocera.co.jp/news/2017/0605\\_ipfa.html](https://www.kyocera.co.jp/news/2017/0605_ipfa.html)

<https://www.kyocera.co.jp/tech/sofc.html>



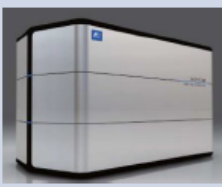




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# Japan – Going up in size -status 2018

Goal in the Roadmap	Progress
<ul style="list-style-type: none"> <li>For business and industry use, aim at launching SOFC cogeneration type in 2017.</li> </ul>	<ul style="list-style-type: none"> <li>Demonstrations have been progressing in several models steadily, and expected to be launched in 2017.</li> </ul>

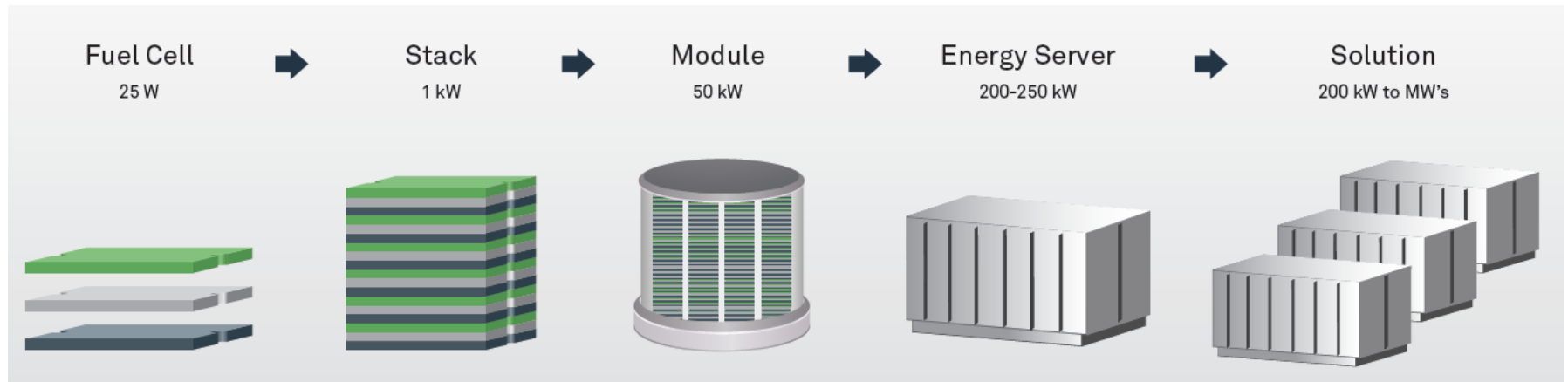
## Development and Demonstration of SOFC units for business and industry

Manufacturer	Denso	Miura	Fuji Electric	Hitachi Zosen	Mitsubishi Hitachi Power Systems (MHPS)
	Demonstration model				
Appearance					
Output	5 kW	5 kW	50 kW	20 kW	250 kW
Electrical generation efficiency (target value)	(under consideration)	50 %	50 %	50 %	55 %
Total efficiency (target value)	(under consideration)	90 %	80 %	80 %	73% (hot water) 65% (steam)
Major envisioned demand	Barbers and hair salons, small stores, family restaurants		Gym, welfare facilities, hospitals, small buildings		Data centers, large buildings, and hotels



# USA – Bloom Energy (200 kW system)

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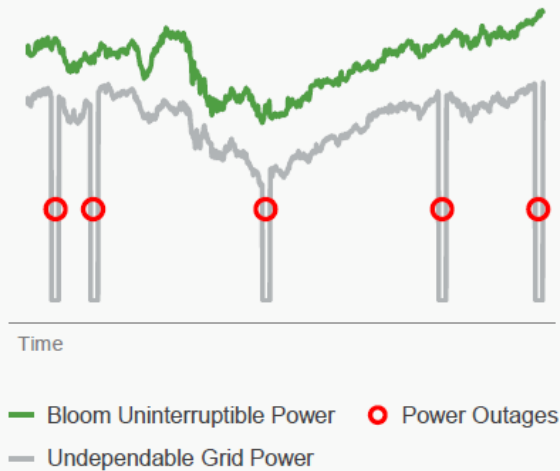
systems beeing sold in 2017



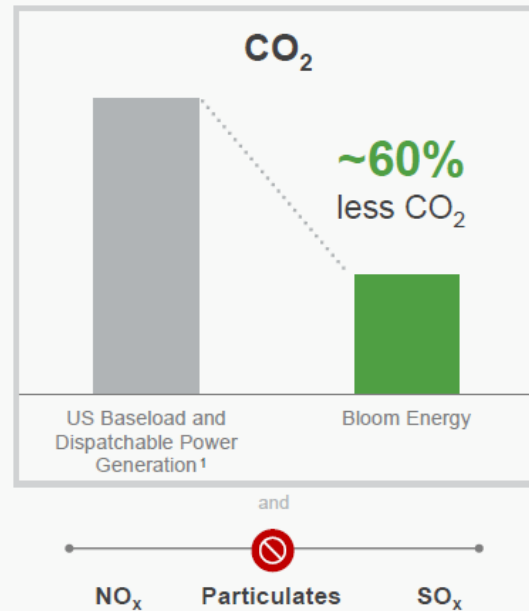
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# VALUE PROPOSITION: BETTER ELECTRICITY

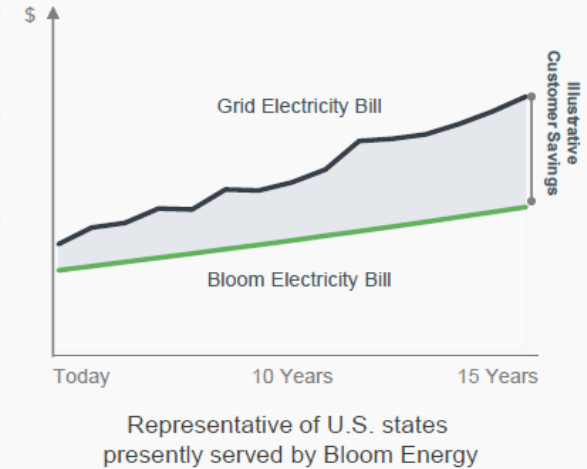
## Reliable and Resilient



## Clean



## Lower and Predictable Cost<sup>2</sup>



Optimized solutions match our customers' needs today and requirements tomorrow

1. U.S. carbon dioxide emitting baseload generation and dispatchable power plant emissions
2. Specific to the markets served by Bloom Energy

Source: Bloom Energy



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# BLUE CHIP CUSTOMERS ACROSS VERTICALS

CLOUD SERVICES AND  
TECHNOLOGY



CONSUMER AND RETAIL



EDUCATION



MEDIA AND TELECOM



FINANCIAL SERVICES



HEALTHCARE



Rapid Commercial Adoption, Including 25 of the Fortune 100 and 42 of the Fortune 500

Representative sample for select verticals

Source: Bloom Energy



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# INTERNATIONAL C&I MARKET OPPORTUNITY

## \$608Bn

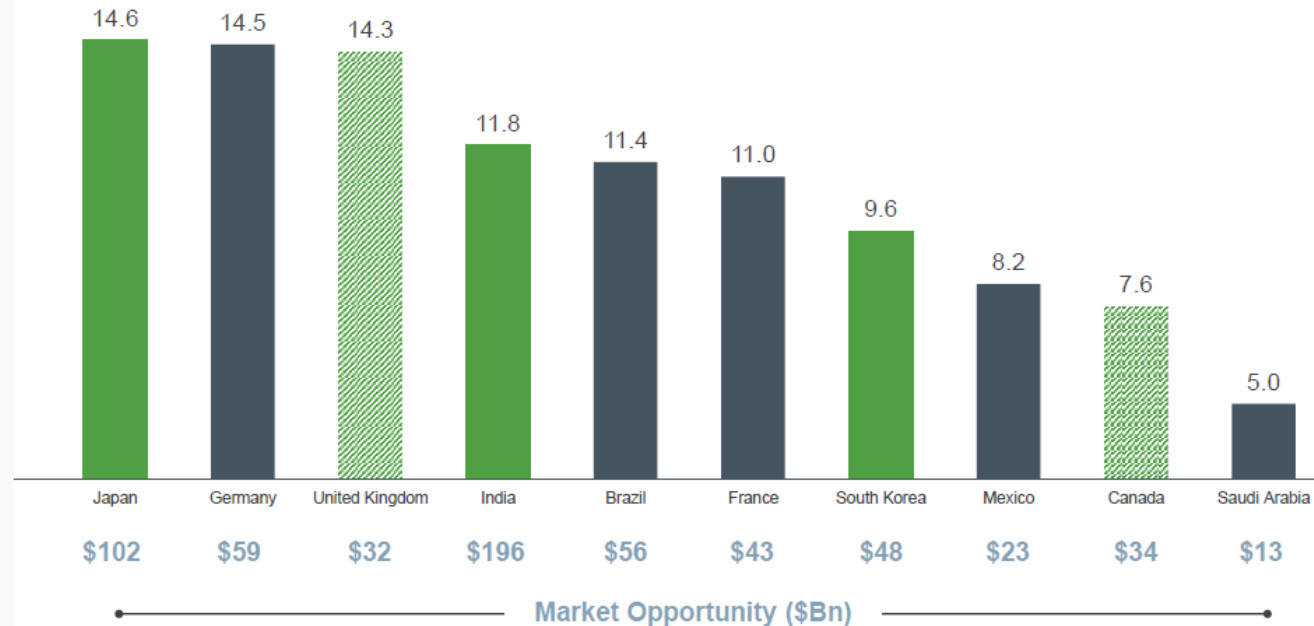
market opportunity for  
the ten largest  
international markets<sup>1</sup>

1. Excluding China and Russia
2. Power price data from IEA, Indian Ministry of Power, National Electric Energy Agency of Brazil and Saudi Electricity and Cogeneration Regulatory Authority

## Expansive Growth Opportunity

Top Ten Countries by Generation<sup>1</sup>

Industrial Power Price (¢/kWh)<sup>2</sup>



Current Bloom Countries Active Market Development Non-Bloom Countries

Source: Bloom Energy

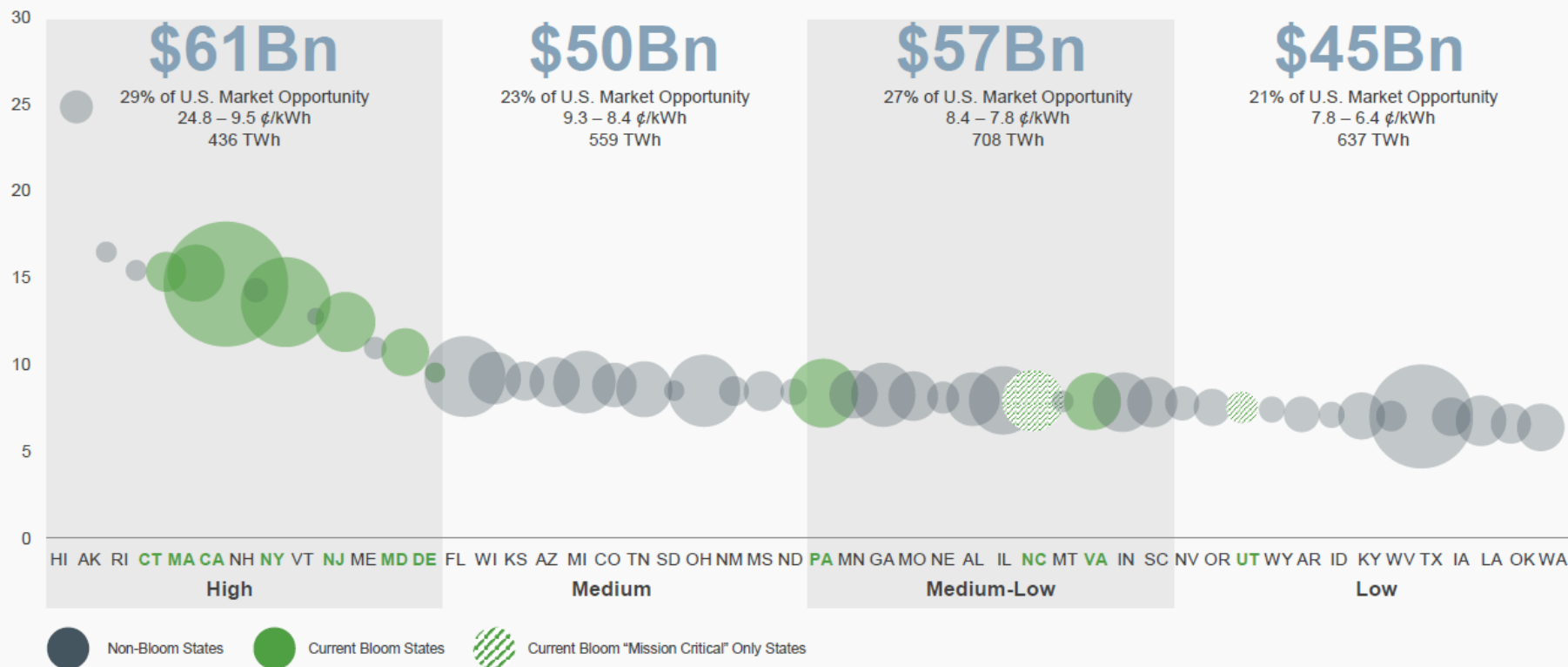


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# U.S. C&I ELECTRICITY MARKET OPPORTUNITY<sup>1</sup>

C&I Power Price (¢/kWh) / C&I Revenue (\$Bn)



1. Source: EIA data for commercial and industrial customers as for the year 2015

Source: Bloom Energy

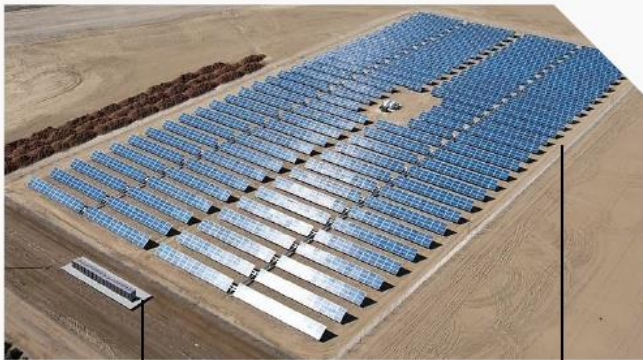


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# USA – Bloom Energy

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## POWER DENSITY COMPARISON



1 MW Solar PV Facility

1 MW Bloom Energy



Solar Requires  
**~12,500% More Space**  
than Bloom<sup>4</sup>

Bloom's power density is  
well suited to customer  
on-site solutions

Source:  
Bloom Energy



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# USA – Bloom Energy (200 kW system)

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- On the stock market since 2018
- Decreases customers dependence on electrical grid
- 25 of Fortune 100 as customers (especially for US datacenters)
- 60 % less CO<sub>2</sub>, compared to “US Baseload”
- May be combined with batteries to decrease the dependence on grid further
- Cost of a Bloom Energy system (\$/kW) decreased with 48 % between 2015 and 2018
- Cheap natural gas on the US market



# USA – Bloom Energy (200 kW system)

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- Sold 25.7 MW (Q4 2018)
  - Growth rate of 30 %
- Current price approx. 7000 USD/kW
- Main markets USA and South Korea
- Biogas is now a possible fuel
- Bloom 7.5 platform will be introduced in 2019, enabling 50 % more power with the same footprint
- Combination with battery solutions decreases the dependency on the grid
- Backlog of 9-12 months

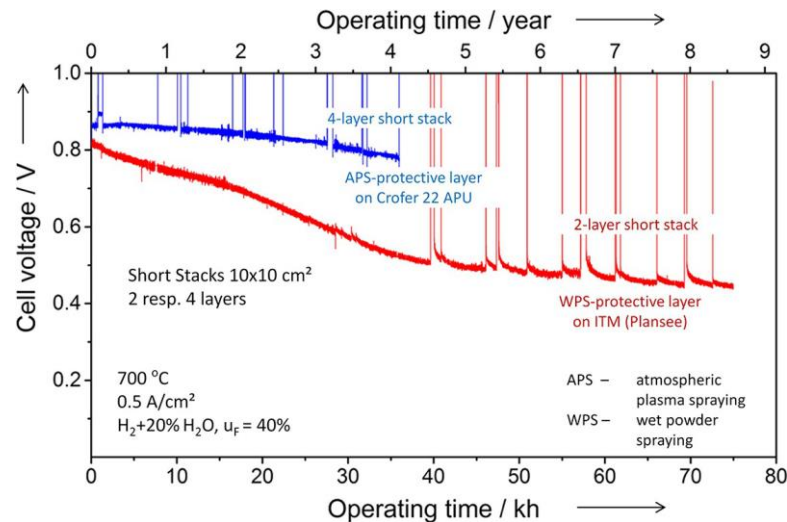


# Germany – Lifetime test at FZJ

- Lifetimes of 11 years reached (stopped after 100 000 h working time) for stack in laboratory environment (FZ Jülich).
- 11 years “old technology” [even longer lifetime with technology of today expected]
  - No “new” similar long-time tests being started at FZJ



Courtesy of FZJ



Blum *et al*, *Energy Tech.* (2016)



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# Some numbers on electrical efficiency

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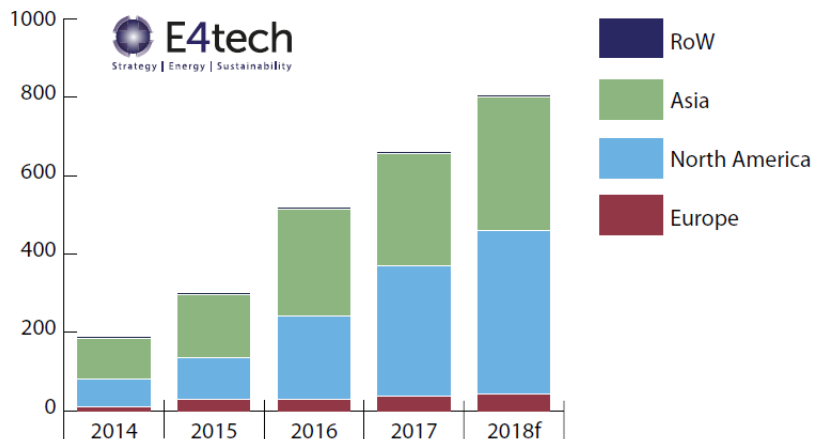
- An electrical efficiency of 60 % (LHV) for an SOFC system as small as 1.5 kW SOFCs (Solid Power)
- An electrical efficiency of 72.5 % (LHV) for a 200 kW SOFC system under development by SOFCMAN in China.
- Mitsubishi Hitachi Power Systems, SOFC+GT
  - Currently 250 kW in demonstration phase, 55 % electrical efficiency
  - Future 100 MW+ systems of electrical efficiencies of 73+ %



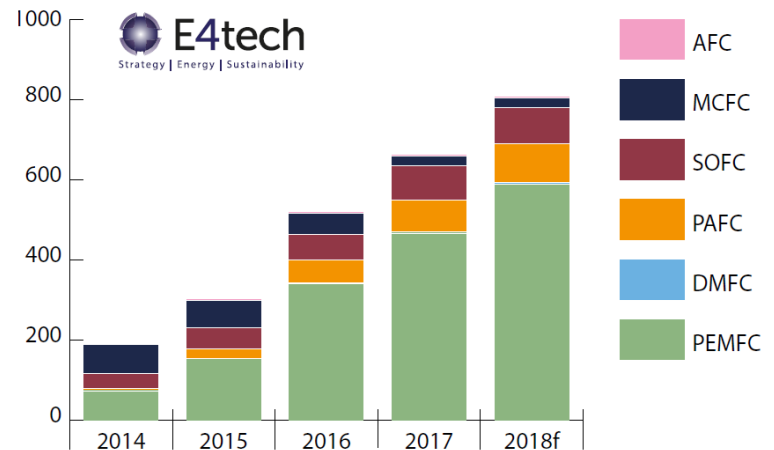


# Some numbers (not limited to SOFC)

Megawatts by region of adoption 2014 - 2018



Megawatts by fuel cell type 2014 - 2018



# Introduction to fuel cells

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- ... in 5 years the fuel cells will ... fuel cells are here
- Life length (durability) 11 years in lab
- Cost Ok for specific nice market
- No fuel available... Natural gas grid on many markets
- High electrical efficiencies
- Grid



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# Questions and Comments

