Honda Clarity

Point of Use Production of Low Cost, High Purity H2 by Efficient Steam Reforming of Natural Gas

Power + Energy

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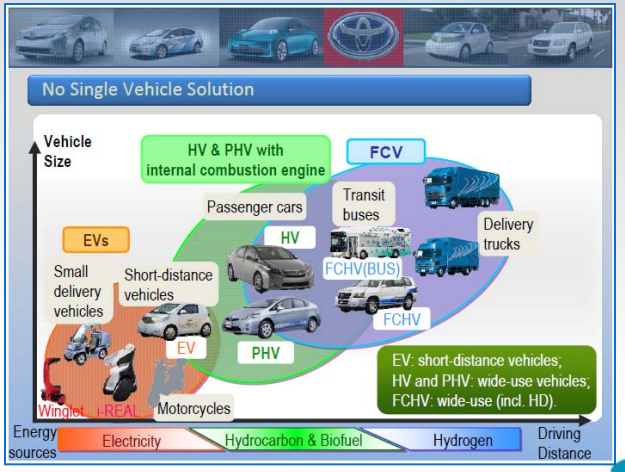
H2 fuel cell vehicles joining the vehicle fleet need fuel

- Vehicle manufacturers have spent $Bns to develop H2 fuel cell vehicles.
- Initial commercial introduction is planned for 2015.
- H2 fueling infrastructure is lagging and is becoming the ‘pacing’ factor for vehicle roll-out.
- H2 generation & distribution infrastructure varies by country and region leading to inconsistent H2 availability and widely varying costs.
- On-site H2 generation can reduce the scale of individual investment decision and generate H2 at a consistent and low cost.

Source: Daimler



Source: Toyota

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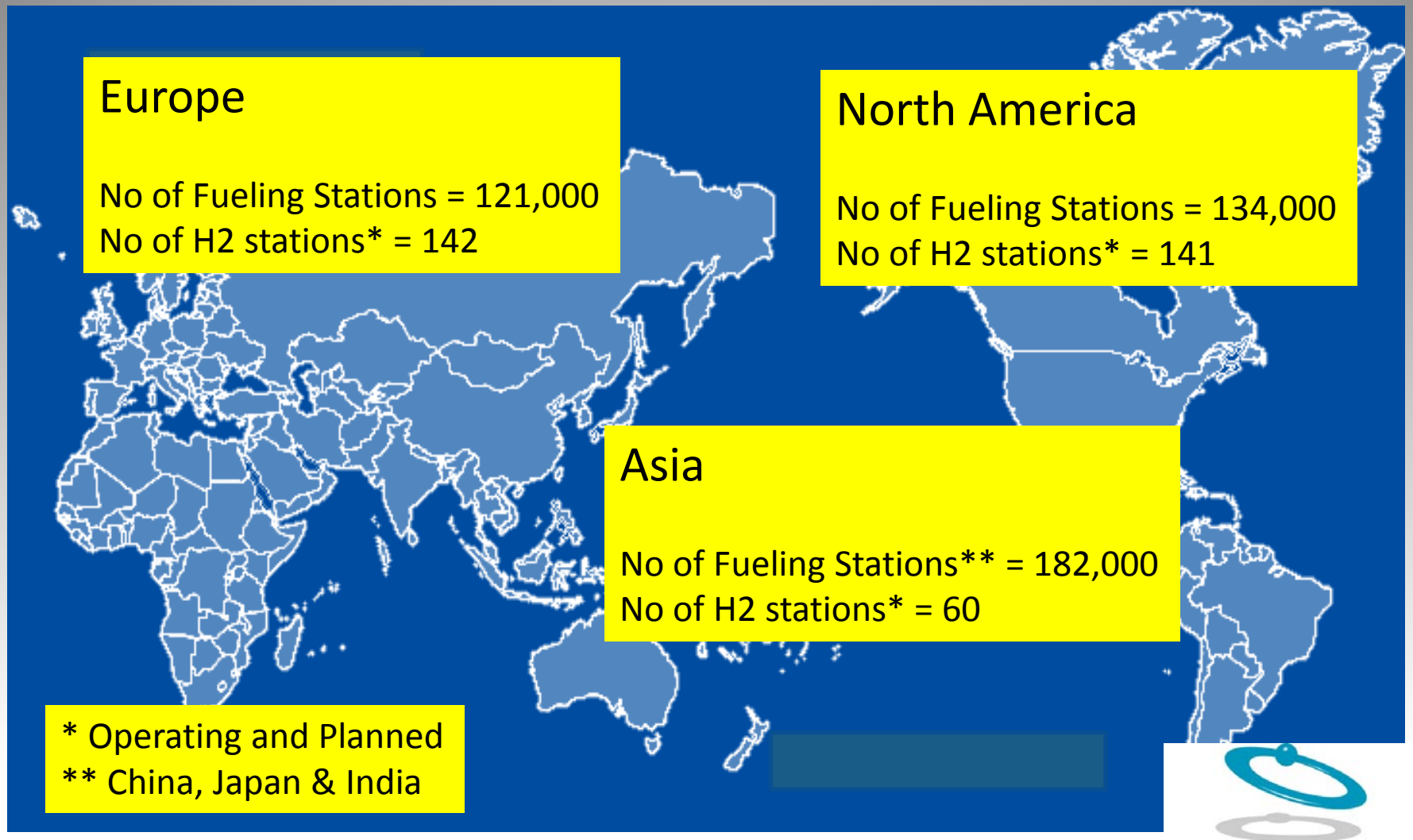
Hydrogen Fueling Stations – A Huge Market Potential !



Sources: h2stations.org, retail-index.com, Wikipedia

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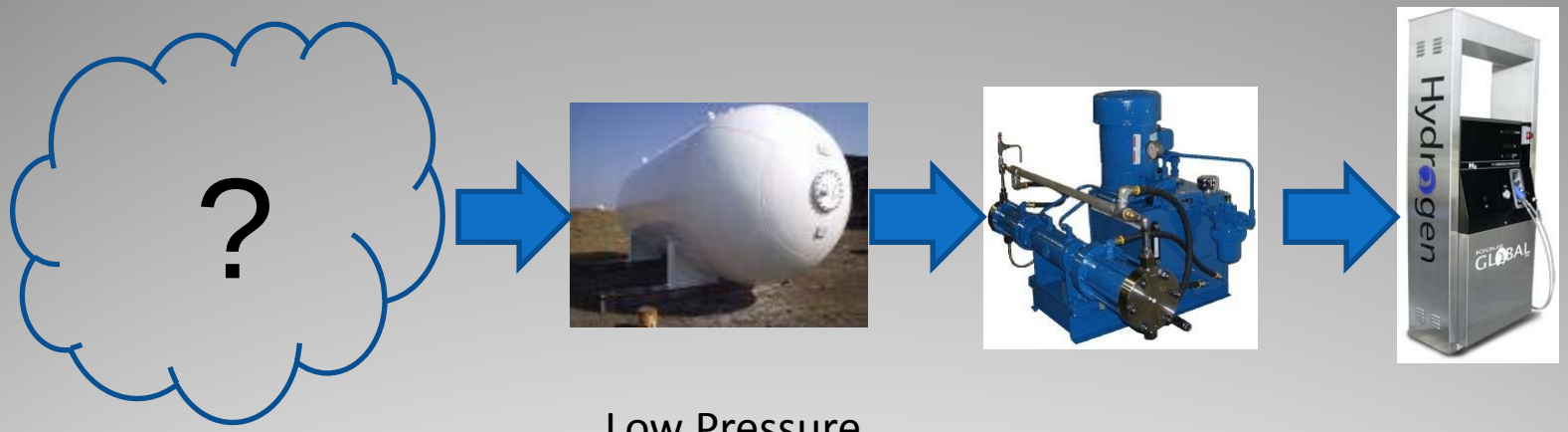
Today's challenge is to improve the availability of low cost, high purity H2!



H2 Source

Low Pressure Storage

Compression

Dispenser

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Hydrogen Supply Options*

Large Scale Production and Distribution

Capacity 150TPD +
Serves ~ 300 stations
Serves ~ 30000 vehicles/day
Capital ~ $500M

- Served area limited by distribution costs
- Significant up-front investment required

Scale too big to support vehicle roll-out

Conventional On-Site Steam Reformer

Capacity 100 - 650kg/day
Serves 1 fuel station
Serves ~ 20 - 130 vehicles/day
Capital ~ $1.25 - $1.75M

- Requires a local supply of natural gas (or liquid fuel)
- Station-by-station investment

Large footprint, operation and maintenance challenges

Power + Energy Micro-Channel H2 Generator from Natural Gas

Capacity up to 650kg/day
Serves 1 fuel station
Serves ~ 20 - 130 vehicles/day
Capital ~ $0.7 - $1.3M

- Requires a local supply of natural gas (or liquid fuel)
- Station-by-station investment

Compact, automatic operation, minimal maintenance

* SMR technology only

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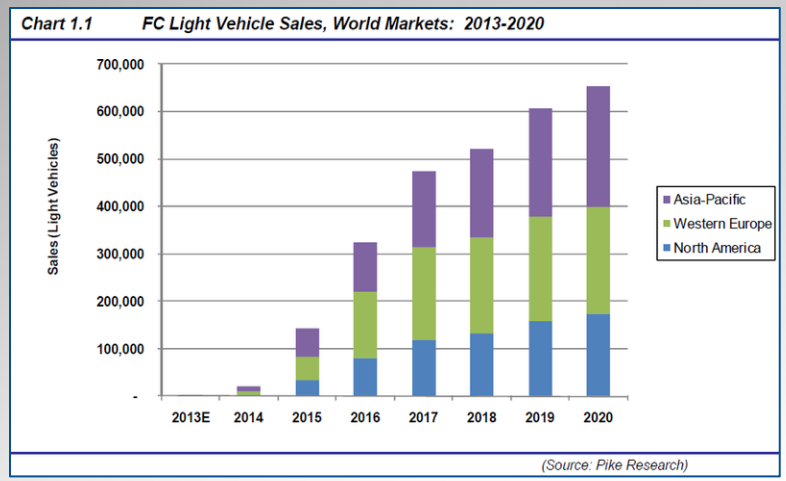
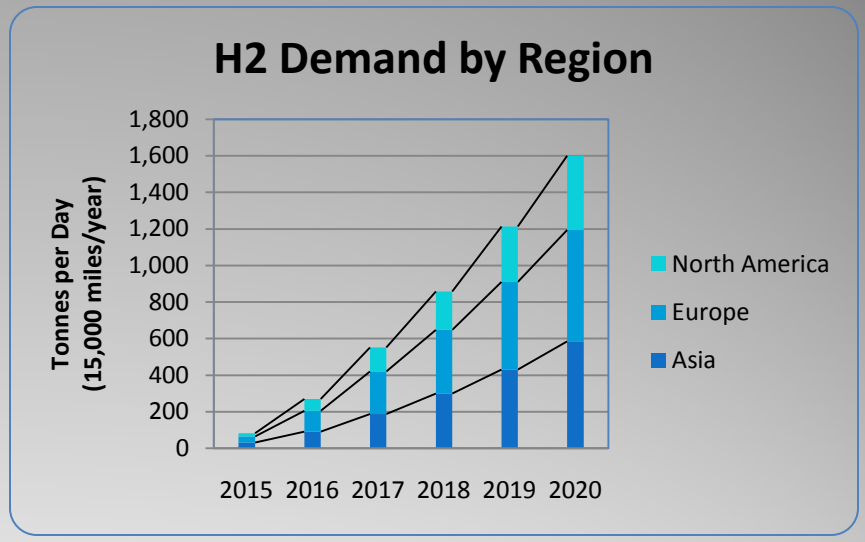
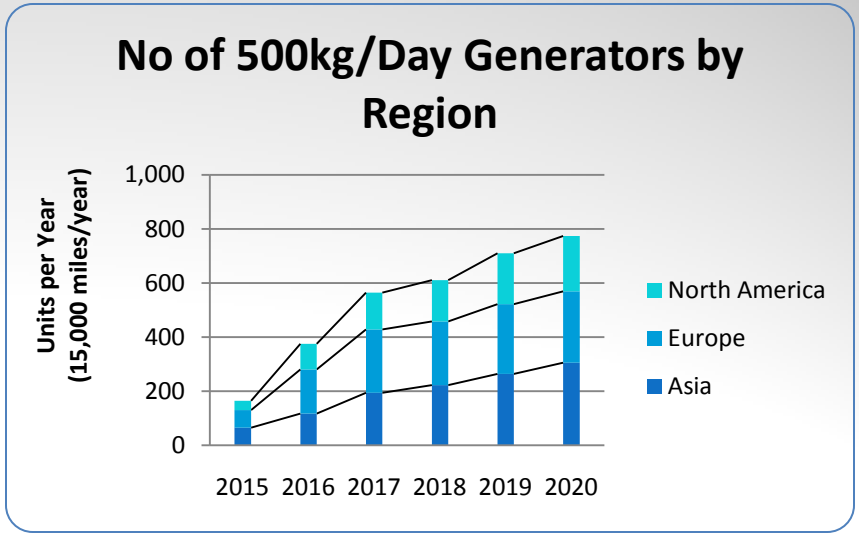
On-site Generation matches H2 capacity to vehicle roll-out

A total of 3,500 x 500kg/day generators will be able to support global demand to 2020.







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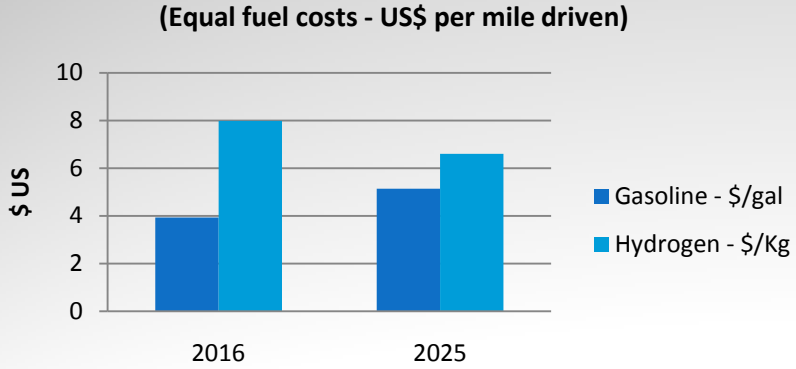
On-site SMR Generation meets H2 cost goals

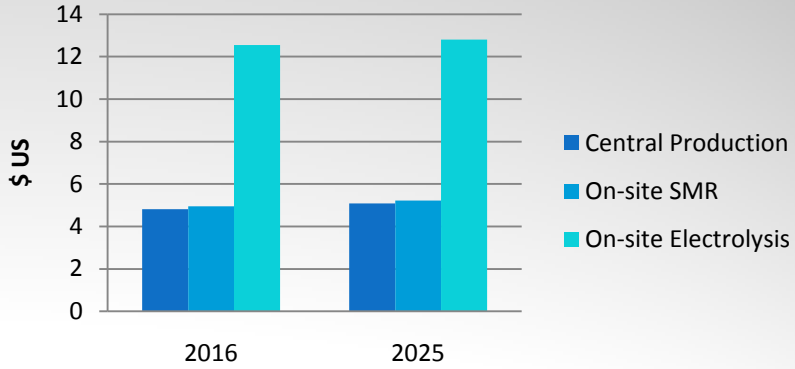
- Hydrogen fuel cost will affect consumer adoption of fuel cell vehicles.
- Hydrogen must be competitive with gasoline, diesel, etc
- The $/mile driven cost of gasoline ICEs will be driven down by rising fuel efficiency standards
  - US CAFE 2016 = 35.5 mpg
  - US CAFE 2025 = 56 mpg
- Hydrogen price must cover - Hydrogen Gas cost + Fueling Station Cost + Profit !

Breakeven H2 Pricing vs Gasoline



Source: P+E calculations based on Honda Clarity performance, 2011 gasoline @$3.50/gal and 3% inflation

Hydrogen Cost at the Dispenser



Source: SFA Pacific 2002 study, 3% inflation

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Micro-channel purification meets H2 purity goals

- SAE J2719/ISO 14687-2-2009 sets the specification for hydrogen for use in PEM fuel cells.
- Carbon Monoxide (CO) and sulphur contamination is harmful to PEM fuel cells
- CO and sulfur are present in SMR H2 from the natural gas and as a reaction by-product
- Ultra-purification is required to meet the CO specification
- Micro-channel membrane purification technology reduces all impurity levels to < 1ppb

	SAE J2719 -2008 ISO/CD 14687-2 - 2009
Impurities	**Parts per Million**
Total Non-Particulates	< 100
Water	< 5
THC	< 2
O2	< 5
N2, Ar	< 100
He	< 300
CO2	< 2
CO	< 0.2
Total Sulfur	< 0.004
Formaldehyde	< 0.01
Formic Acid	< 0.2
Ammonia	< 0.1
Total Halogenates	< 0.05
Particle Size	< 10 um
Particulate Concentration	< 1 ug/L

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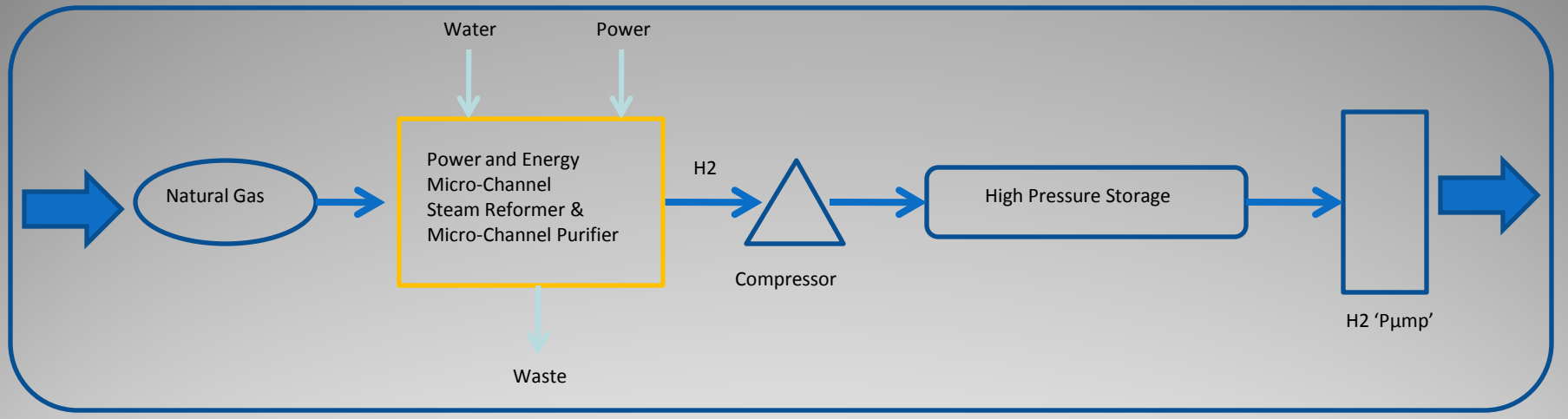
Power + Energy's high efficiency on-site micro-channel H2 generator and purifier is the ideal hydrogen source



Micro-channel Generator

- Generates H2 from CH4 + H2O
- High efficiency design
  - 30 W/cm^2 heat transfer
  - 70 % H2 recovery – balance used for heat generation
- Low temperature operation for durability
- Modular design for easy scale-up

Micro-Channel Purifier

- Extracts H2 from the SMR reformate stream
- Purifies to 99.9999999%
  - Exceeds ISO 14687/SAE J2719
  - CO < 1ppb
  - Sulfur < 1ppb
- Single stage process, no moving parts

Available, scalable, low cost, high purity

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H2 Generation by Micro-Channel Steam Methane Reforming

- Micro-channel design
  - Heat transfer per unit weld length improved 10x
  - Reduces thermal stress by up to 99%
- Scaleable design
  - Up to 650 kg H2/day in one 150mm diameter cell
- Thin-wall micro-channel maximizes heat transfer
  - 30W/cm^2
  - ~ 500 °C operating temperature
- Raffinate combustion provides the energy for the SMR endothermic reaction
- High catalyst surface area to gas flow
  - Gas diffusion length < 500 microns
  - Heat transfer length < 500 microns
- Push button operation, minimal maintenance

Typical SMR technology
Capacity: 650 kg H_2/day
H2 Out purity: < 99.9999%

P+E Micro-Channel SR technology
Capacity: 650 kg H_2/day
H2 Out purity: 99.9999999%

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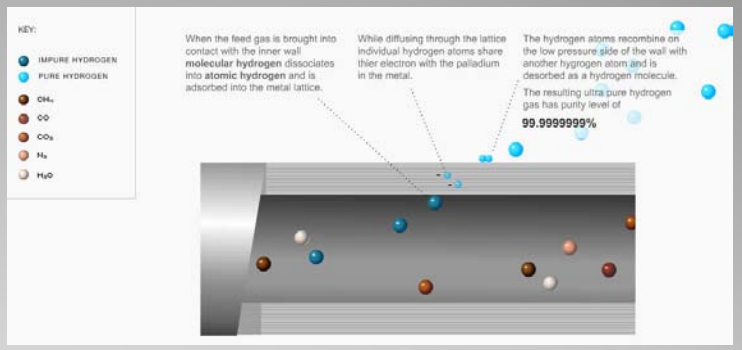
Power + Energy Micro-Channel H2 Purifier

- **Micro-channel purifier**
  - Palladium diffusion principle
  - Solid Pd alloy membrane
  - Developed in partnership with the US Navy for harsh duty applications
  - Closely packed membrane arrays
  - Capacities of up to 200kg/day from a single micro-channel array
- **Deposited Membrane purifier**
  - Palladium diffusion principle
  - Pd alloy deposited on porous substrate
  - Lower cost
    - Less Palladium required
    - Lower processing costs

Palladium Diffusion



Micro-channel purifier

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Power + Energy Experience

Founded in 1993

US Government funded R&D in hydrogen purification and generation

Extensive customer base in the LED, PV, Semiconductor, renewable energy industries and vehicle fueling

China customers in Dalian, Chengdu, Shanghai and Beijing

Partnered with WahLee Industrial Corp to serve the Chinese market

P+E purifiers at Shell fueling station Torrance, CA

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Conclusion

- Fuel cell vehicles are coming
- Today's challenge is to improve the availability of low cost, high purity H2
- P+E's on-site micro-channel generator + purifier meets the challenge
  - Stand-alone – no need of for expensive infrastructure
  - Low cost – supports H2 pricing < gasoline equivalent
  - Quality – exceeds SAE/ISO standards for H2 quality

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