# DISTRIBUTED GENERATION – CHOICES FOR A SUSTAINABLE ENERGY FUTURE

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# INTRODUCTION

- Distributed resources
  - Distributed Generation
  - Distributed Storage

**Putting generation and storage as close to the point of consumption as possible**

- Typical sizes:
  - 5 kW to 500 kW connected at LV networks
  - 2 MW to 10 MW connected at MV networks

# APPLICATIONS

- Standby/Back-up power
- Peak Shaving (onsite loads)
- Baseload (onsite loads)
- Combined heat and power
- Power Quality
- Electricity Sales
- Ancillary Services
- T&D support
- Microgrid applications

# WORLDWIDE GROWTH OF DR MARKET

| | 2000 | 2004p | 2008p |
|---|---|---|---|
| Worldwide installed Capacity (GW) Developing and Emerging Markets) | 3266 | 3554 | 3872 |
| Worldwide total Capacity Additions (GW) | 111 | 114 | 119 |
| Distributed Generation Share | 10% | 21% | 37% |
| Worldwide Distributed Generation Annual Additions (GW) | 11.2 | 24 | 44 |

# WHY IS DR BECOMING POPULAR?

## Possible Reasons:

- Natural gas prices are lower
- Transmission botlenecks
- Summer price spikes
- Low power quality is seen everywhere
- Low reliability of present electricity service

# DR TYPES

- **Distributed Generation**
  - Microturbines
  - Advanced engines
  - Fuel cells
  - Wind Power
  - Solar Power

- **Distributed Storage**
  - Compressed air
  - SMES
  - Battery
  - Flywheel
  - Supercapacitors

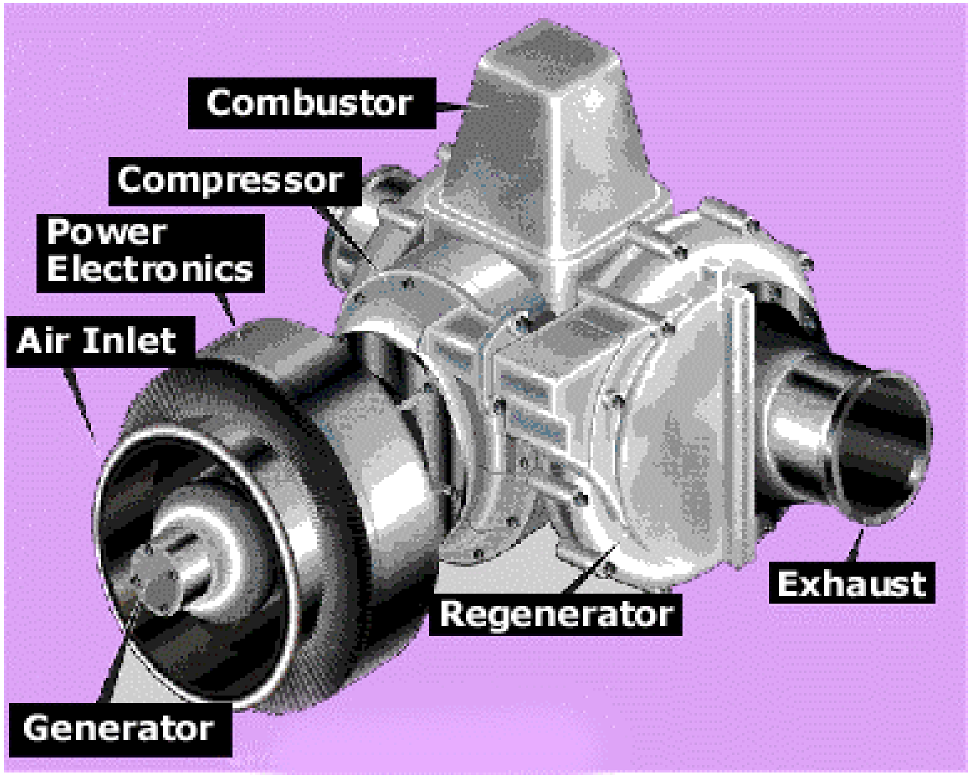
# BENEFITS OF DR

- Modular, avoids high first-time costs and allows fast payback
- Fewer large power plants and overhead power lines
- Impact on Emissions Reductions
- Lower T&D costs
- Higher efficiency
- Improved reliability
- CHP - Cogeneration of heat and electricity can improve overall energy efficiency at the plant

# DRAWBACKS OF DR

- Still small in size to participate in market transactions
- Not enough economic incentives to participate
- Control issues – synchronization, post-disturbance reconnection
- Availability issue
- Cost is still an issue

# MICROTURBINE



# MICROTURBINES

- Operates on the same principle as GT
- Compressor and generator are typically driven at high speeds (sometimes above 120,000 rpm)
- Power Conditioning is required at output
- Specially effective for CHP
- Uses mostly natural gas as fuel; other fuels, such as diesel, propane, and kerosene are possible
- $NO_x$ and CO emission not much concern

# ADVANCED ENGINES

- **Also known as Internal Combustion engines or reciprocating (recip) engines**
- **Require three ingredients to function: fuel, air, and an ignition source**
- **Two categories based on the ignition source:**
  - **Spark ignition (SI)**
  - **Compression ignition (CI).**
- **Engines operating on natural gas have recently been developed. Footprints are in the order of 50 $kW/m^2$**

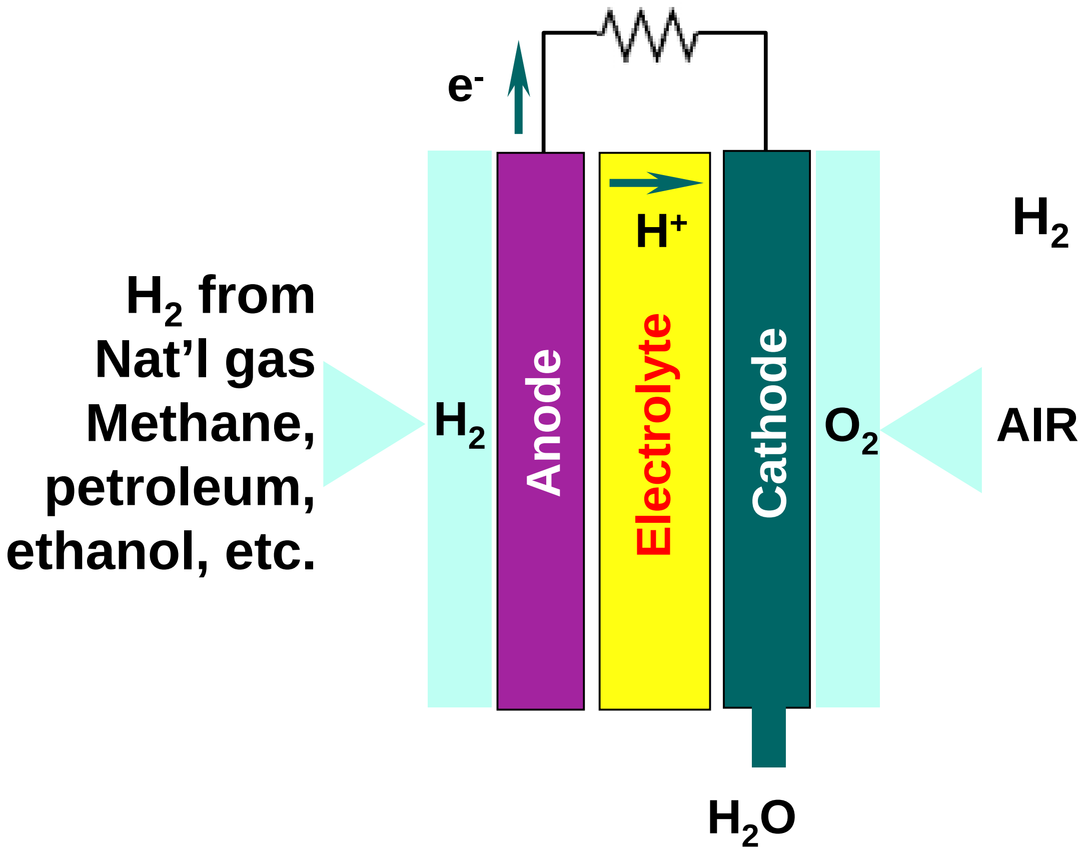
# ADVANCED ENGINES, cont'd

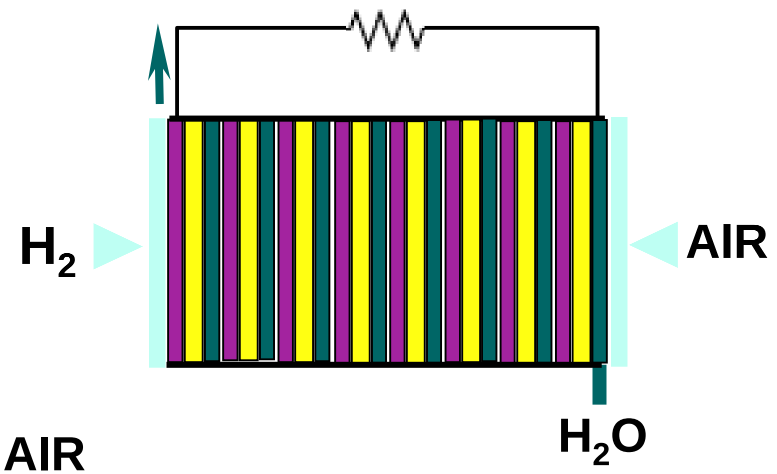
- A two-stroke engine is more efficient than a four-stroke engine
- A four-stroke engine produces lower emissions than a two-stroke

# ADVANCED ENGINES, cont'd

- Gensets now available in the 5 kW to 20 MW range
- Installed capital cost of $400 to $600/kW
- Operation and maintenance costs of 0.5 cents/kwh
- Produce 0.022 to 0.25 lb/kWh of $NO_X$ emissions when operated with diesel fuel
- Produce 0.0015 to 0.037 lb/kWh of $NO_x$ emissions when operated with natural gas.
- DOE - Advanced Reciprocating Engine System (ARES)—increase efficiency to 50 percent.

# FUEL CELL BASICS

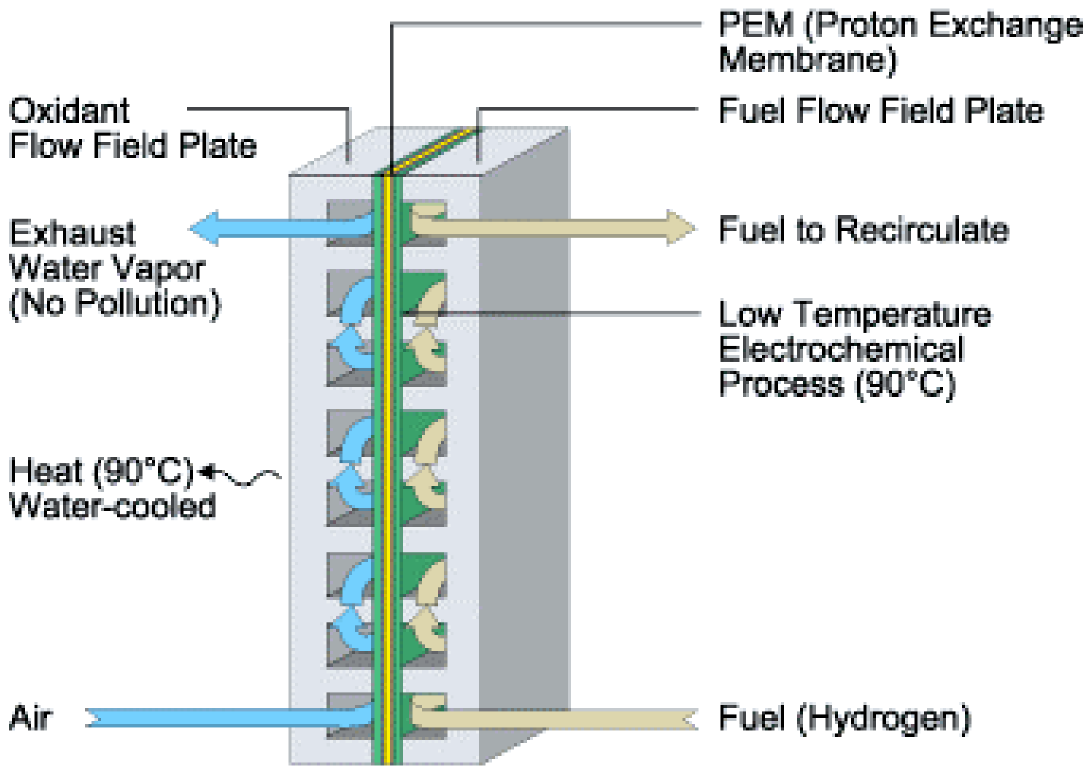



Stack of Fuel Cells

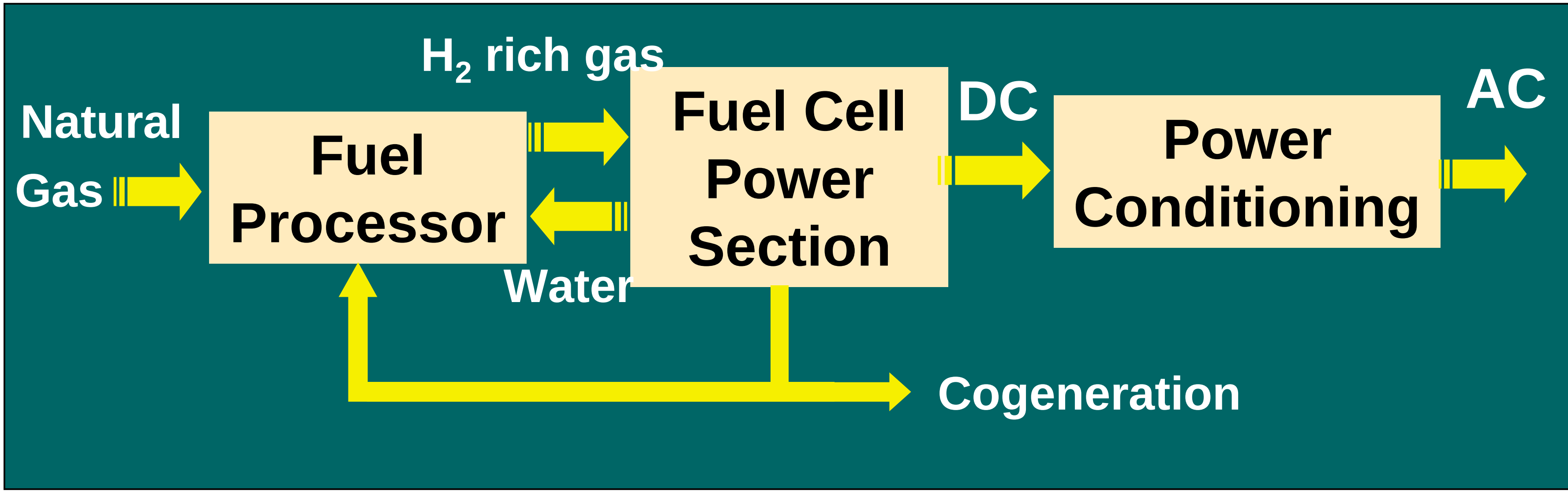
Natural Gas (mostly $CH_4$) + Air (Oxygen) = Electricity + Heat + Carbon Dioxide

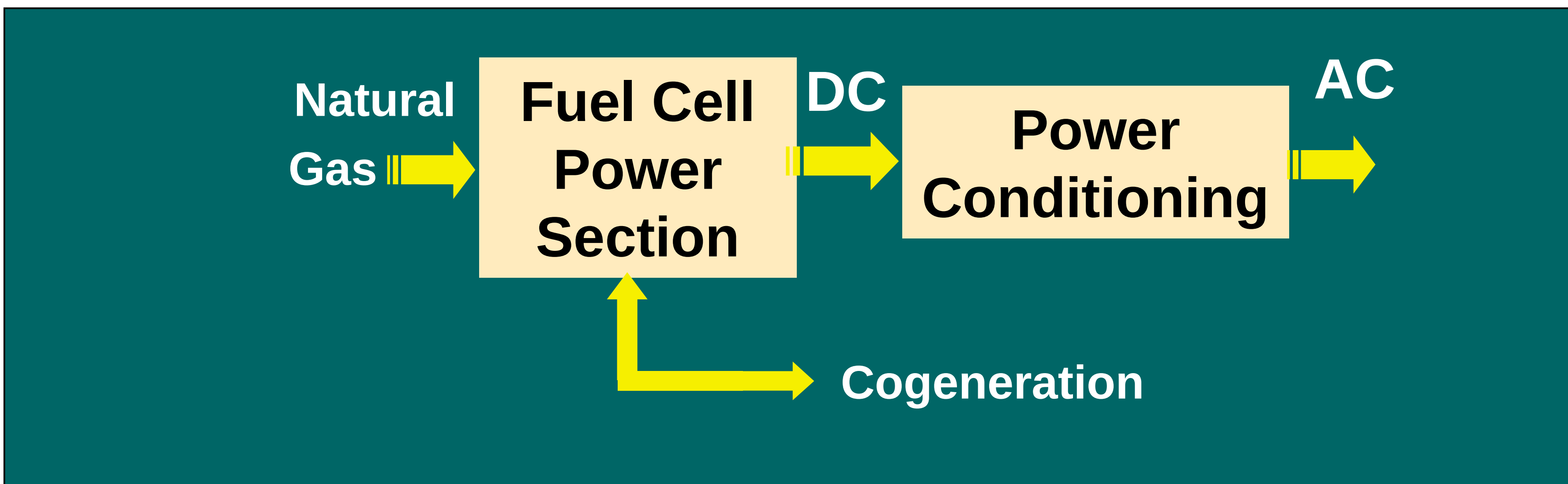
# Ballard's Proton Exchange Membrane



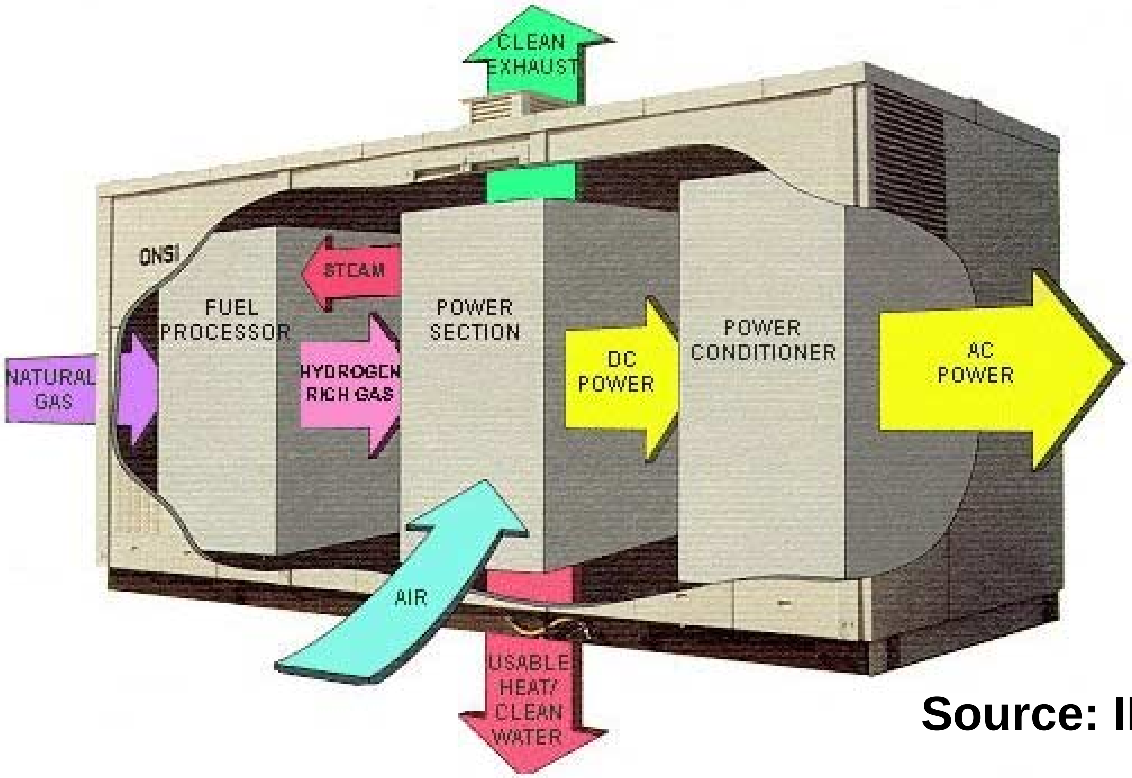

**Source: Ballard Power Systems**

# Fuel Cells – Conventional vs. Newer Models



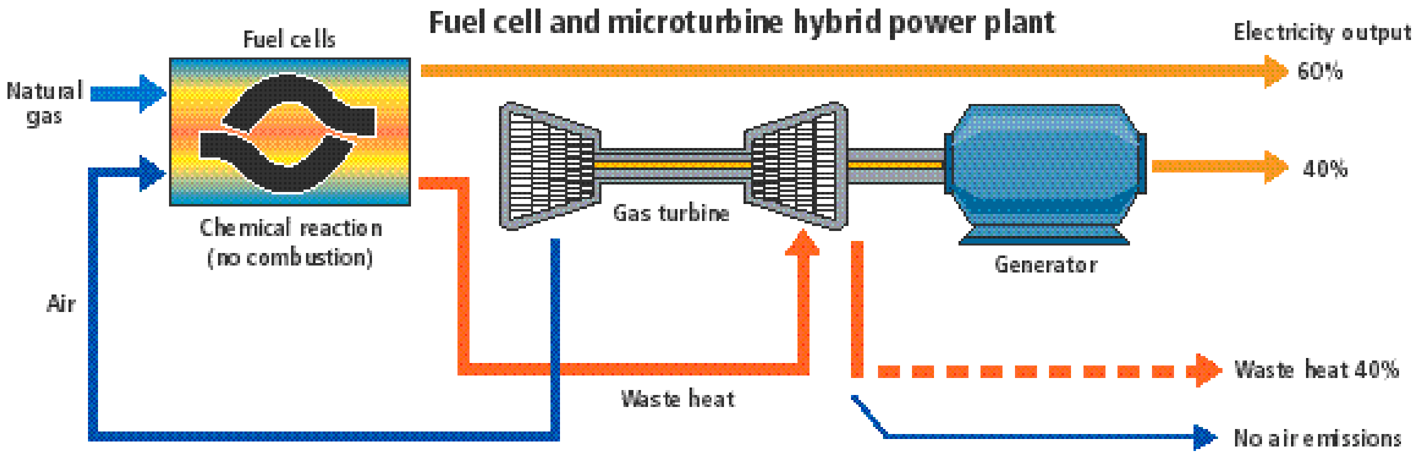
# Commercial Fuel Cells for Power Gen




**Source: IEEE Spectrum**

**1 MW capacity, IFC PC25 installed at Anchorage, Alaska. Operates in parallel with Chugash Electric.**

# Fuel Cells/Gas Turbine Hybrid




**Source: IEEE Spectrum**

# FUEL CELL TYPES

| TYPE | OPERATING TEMP. | PRESENT/ POTENTIAL APPS |
|---|---|---|
| ALKALI | 50 - 250°C | Space vehicles. Possible uses in land vehicles and submarines |
| SOLID POLYMER | 50 - 100°C | Transportation; a host of other applications |
| PHOSPHORIC ACID (PAFC) | ~ 200°C | Medium-scale CHP. 200kW units in commercial prod. |
| MOLTEN CARBONATE | ~ 600°C | Medium to large-scale CHP. 1-2 MW unit trial systems being built. |
| SOLID OXIDE (SOFC) | 500 - 1000°C | All sizes of CHP. 2kW to multi-MW units. Least developed; high potential |

# DG COMPARISONS

| | Efficiency | Size | Cost |
|---|---|---|---|
| Micro-turbine | 28 ~ 33% | 25 ~ 300 kW | $750 ~ 900 /kw |
| Recipro-cating engines | 28 ~ 37% | 5 kW ~ 20 MW | $400 ~ 600 /kw |
| Fuel Cells | 30 ~ 40% | 2 kW ~ 250 kW | $750 ~ 900 /kw |
| Gas Turbines | 25 ~ 40% | 500 kW ~ 20 MW | $650 /kw |

# SOLAR POWER

- **Conversion of solar energy directly to electrical energy**
- **Main barrier is the high cost of PV systems, US$ 6000/kW being a typical figure**
- **Power output is directly proportional to the surface area of the cells, and footprint sizes are thus large (0.02 kW/m$^2$)**
- **Typical applications: installations of < 100 kW building rooftops; dispersed; remote**
- **Energy storage is usually required**
- **BOS cost is significant.**

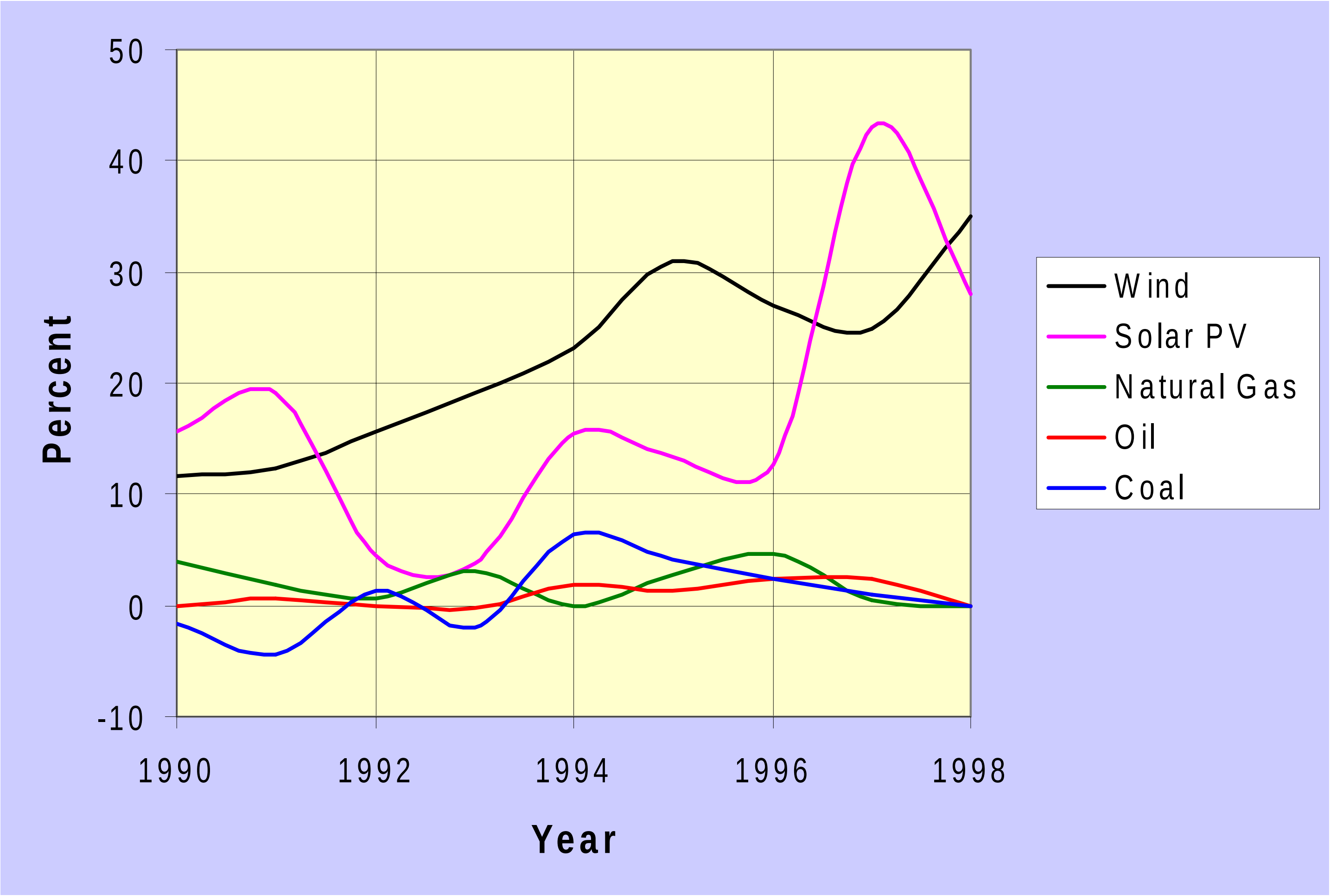
# WIND POWER

- In 1997, total US wind electric generating capacity stood at 1,620 MW
- Market is growing by 40% worldwide annually
- Typical systems range from 30 kW for individual units to 75 MW for wind farms
- Rotor construction is either variable blade angle (pitch regulation) or non-variable
- Either synchronous or induction generators are used to convert to electrical energy
- Add-on capacitors are required with induction generators for reactive power output

# WIND POWER

- ORNL study found it is possible to integrate new wind resources of 50 to 100 MW without the need for significant T&D upgrades
- Utilities may experience difficulty controlling system voltage
- SCE experiences periodic voltage limitations on its 66 kV system in Tehachapi) with a wind plant using conventional induction machines
- Accurate wind plant output forecast can add value to utility operations and scheduling

# Worldwide Growth Rate of Wind and PV



# PROVIDING IMPETUS FOR RENEWABLES

**Impetus for renewables installations will come from:**

- **Funds made available from system benefit monies (currently 13 states)**
- **Renewable Portfolio Standards (8 states)**
- **Net metering (23 states)**
- **State tax incentives, low interest financing**
- **Manufacturing production incentives**
- **Green energy pricing**

# TECHNICAL ISSUES

- **Integration with the existing utility network**
- **Role of power electronics**
- **Impact on power quality**
- **Impact on reliability**
- **Impact on environment**
- **DR modeling for improved stability of operation**

# NON-TECHNICAL ISSUES

- Pricing issues – an economic issue
- Increasing market penetration
- Regulatory issues
- Institutional barriers
- Business Practices

# GRID INTEGRATION ISSUES – COORDINATED CONTROL

- **Price signals for coordinating the operation of the power system in the emerging competitive market**
- **DG start-up times are fast; they can respond to price signals effectively**
- **Large generation companies will continue to exercise market power**
- **New incentives must be given to DG companies for DR to enter the market in large quantities**

# GRID INTEGRATION ISSUES – COORDINATED CONTROL, cont'd

- **Numerous distributed generators might adversely impact system stability and reliability – J. Cardell (FERC) and R. Tabors**
- **Numerous distributed generators might adversely impact harmonic injection**
- **Control issues – synchronization, post-disturbance reconnection, voltage regulation and Frequency control due to intermittent generation**
- **Availability issue – prediction problem**

# GRID INTEGRATION ISSUES – ROLE OF POWER ELECTRONICS

- Where are they needed:
  - Interface for DR
  - Standards for PV and wind
  - Custom Power and FACTS devices
  - Microturbines, Fuel cells
- Requirements
  - Fast switches – IGBT, GTO, MCT
  - New material - SiC
  - Negligible harmonics
  - Capability for producing reactive power

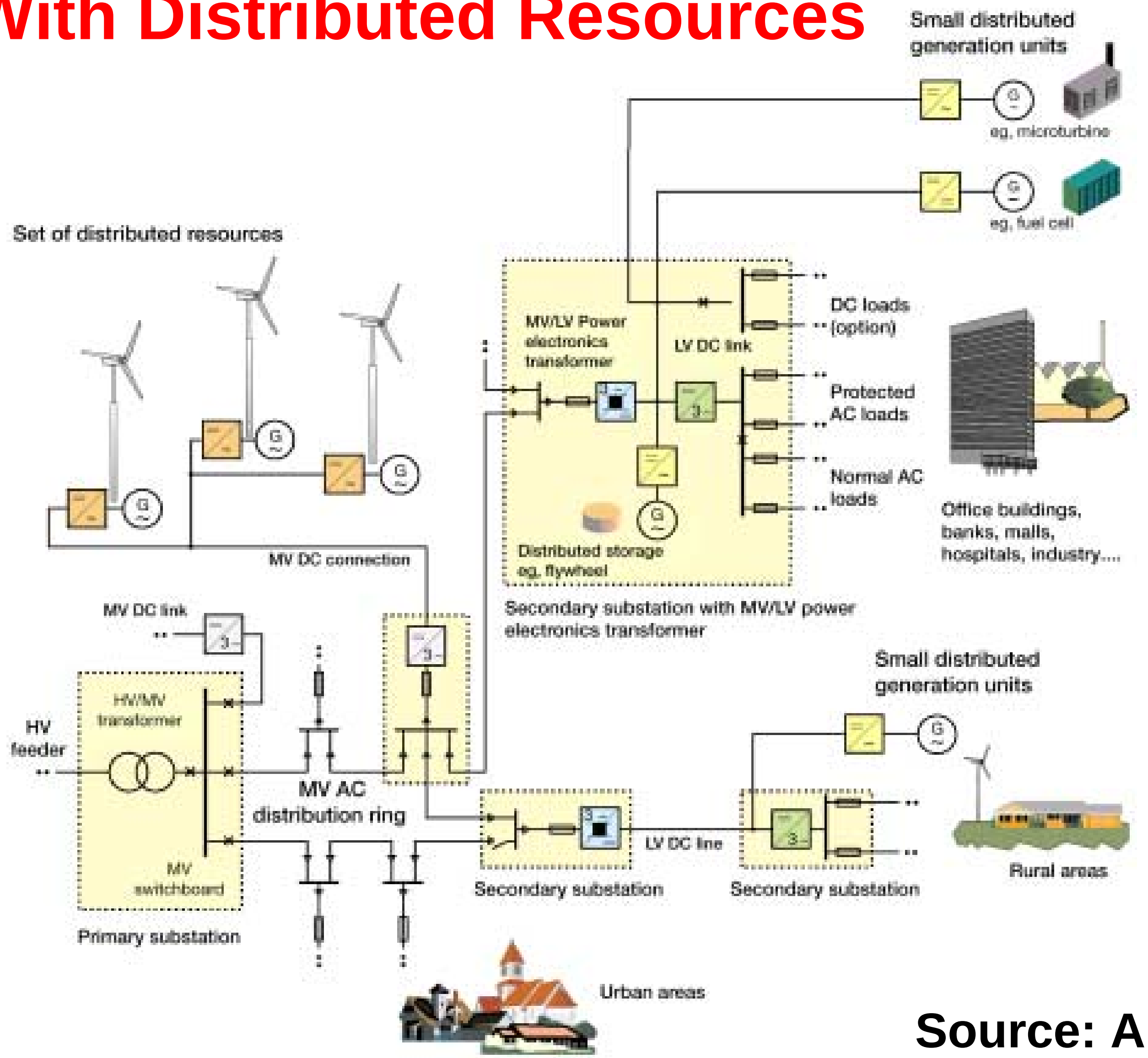
# GRID INTEGRATION ISSUES – IMPACT ON POWER QUALITY

- **A PQ problem is any voltage, current, or frequency deviation that results in the failure or misoperation of customer equipment**
- **PQ includes voltage sags and swells, flicker, transients and harmonics**
- **PQ problems result in productivity losses estimated to cost U.S. businesses $400B /yr**

# GRID INTEGRATION ISSUES – IMPACT ON POWER QUALITY

- DS systems can correct the problem in the first cycle and can be sized to provide a few seconds or minutes of protection
- IEEE 519 recommends limits on harmonics. Updates may become necessary for DR

# Improving Power Quality With Distributed Resources




**Source: ABB**

# PRICING WITH DG

**Transmission line pricing is difficult with DR:**

- **Line charges are not involved if DG is used locally**
- **However, DG leads to lower transmission losses even if used locally**
- **Sometimes DG can be located far from load centers (e.g. wind and solar PV).**
- **Distance-related transmission line charges would make DG more costly to reach customers in urban areas**
- **Transmission pricing based on full cost recovery using two fees: energy charges and capacity/ demand charges**

# ENVIRONMENTAL IMPACT OF DG

- Renewables will generally have a positive impact
  - PV and wind have zero emissions
- Other DG have varying impact.

**Nox emissions in lbs/MWh**

| Engine | Micro turbine | Large GT | Fuel Cell |
|---|---|---|---|
| Nat'l Gas: 3.0<br>Oil: 37.0 | 0.1 ~ 0.5 | 0.1 ~ 2.0 | 0.1 ~ 0.2 |

- Texas developing Emissions Regulations for DG

# CONCLUSIONS

- DG holds potential to significantly alter the design and operation of the power delivery system and the nature of the electric utility industry
- T&D application is one of the most cost-effective opportunities for DG application
- Other benefits are improved reliability and PQ

  Laws and regulations still favor central station power plants
- Air quality regulations still favor market power held by holders of emission reduction credits
- No standardized and streamlined permitting processes for DR exist in local/state agencies

# CONCLUSIONS

- What is the future of DR? In what capacities should DR be used in the deregulated environment?
- Should it be for capacity and T&D deferrals?
- Should it be for improving PQ?
- Regulatory, economic and institutional issues will play an important part in determining the rate and scope of implementation of DR
- For DG to increase market share, safe and reliable DG interfaces must be met.  Cost must continue to fall .

# REFERENCES

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**Opportunities for Micropower and Fuel Cell/Gas Turbine Hybrid Systems in Industrial Applications, DOE Report.**

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**Sandia, NREL**