

**Universidad Politécnica de Cartagena**  
**Department of Electrical Engineering**



Doctoral Course on “Industrial Technologies”.

Subprogram “Neurotech, Control, Robotics and Energy  
Management”

**Analysis of Distributed Energy Resources:  
an Introduction to Demand Response**

Cartagena, 2011

# Lesson 8

## Distributed Generation (DG)



## ● Introduction

## ● Distributed vs. Dispersed Generation

- Distributed Gen: Small generation units (15 to 10.000kW) faced in the PS, owned by the user or a utility.
- Dispersed Gen: It is on the side of demand and supply and are used for small consumption (units of 10 to 250kW).
- Type of technologies
  - Conventional: diesel, gas, combined cycle, hydro?
  - Alternative: fuel cells, solar, wind, external combustion engines (Stirling), hydraulic?

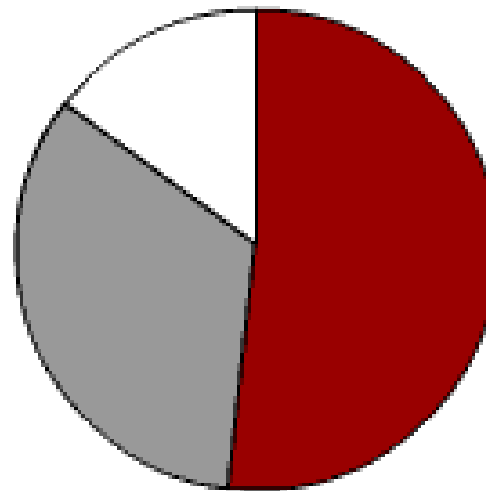


## Block 6

● **Notice: DER = Distributed Energy Resources**

- DER  $\neq$  Generation (DER is often synonymous with DG in the bibliography)
- Do not forget: Demand Response (DR) and Energy Storage (DS)
  - DER has a great potential (source: CEC, California, USA)

**US Commercial/Industrial  
Market Opportunity**



- Current Potential DER Market
- Future Potential DER Market
- Market Portion Not Likely for DER

## ● Centralized and Distributed Generation (I)

- Traditionally: the bulk of electricity production is done in centralized large plants (150-1000MW)

## ● Advantages of Conventional Generation (CG)

- Generation is far from Demand (i.e. a possible impact on customers)
- Can reduce operating costs, fuel, and others ...
  - Physics and economics are on the side of conventional generation
  - Efficiency: eg. Boilers and heat exchangers
  - Volume / surface ratio = generation / loss
  - Power conversion (DC / AC)
  - Protections
  - Labor costs
  - Maintenance cost
  - Transformer stations ... ..



## ● Centralized vs. Distributed Generation (II)

### ● Advantages of DG

- Distributed: The efficiency of DG technologies seems "outrageously" high: up to 40-47%
- Remember: Traditional plant efficiency ranges from 25 to 35+% (coal, lignite, gas-fired boiler,...=
- Provide high quality E (eg. electronic loads)
- Are the unique alternative in areas where there is no conventional supply

### ● These advantages need further explanation:

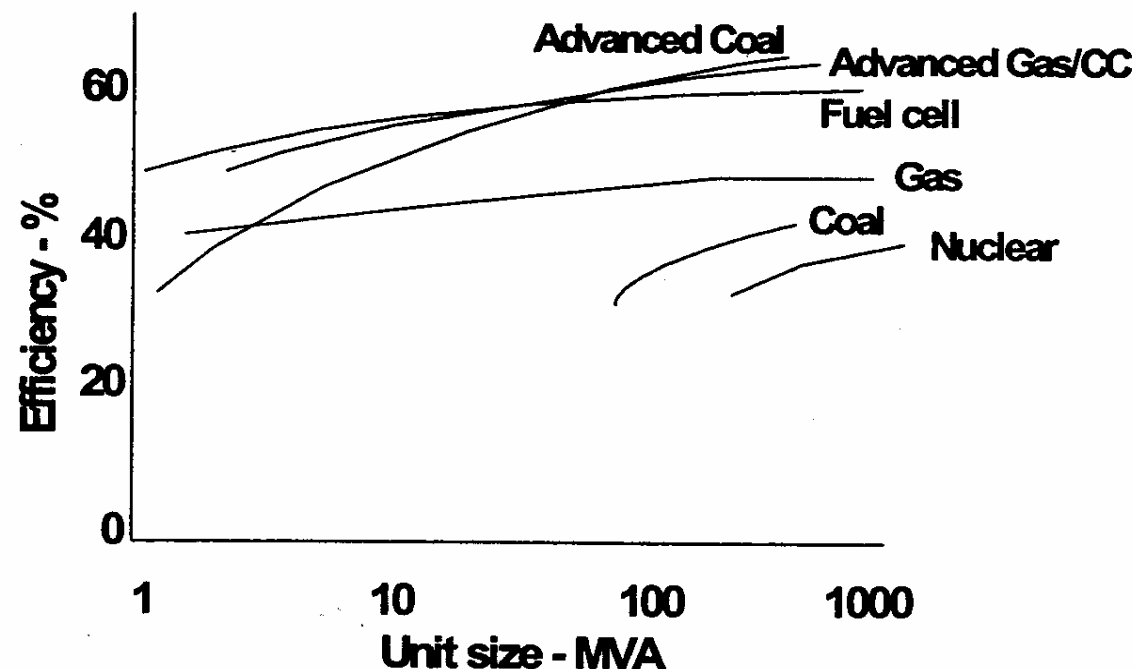
- DG plant technology is more modern (conventional plants have a lifetime from 20 to 50 years)
- It is considered full load operation (up to  $\eta$ ) of the DG units (please, be careful with DG datasheets and webs)



### Centralized vs. Distributed Generation (III)

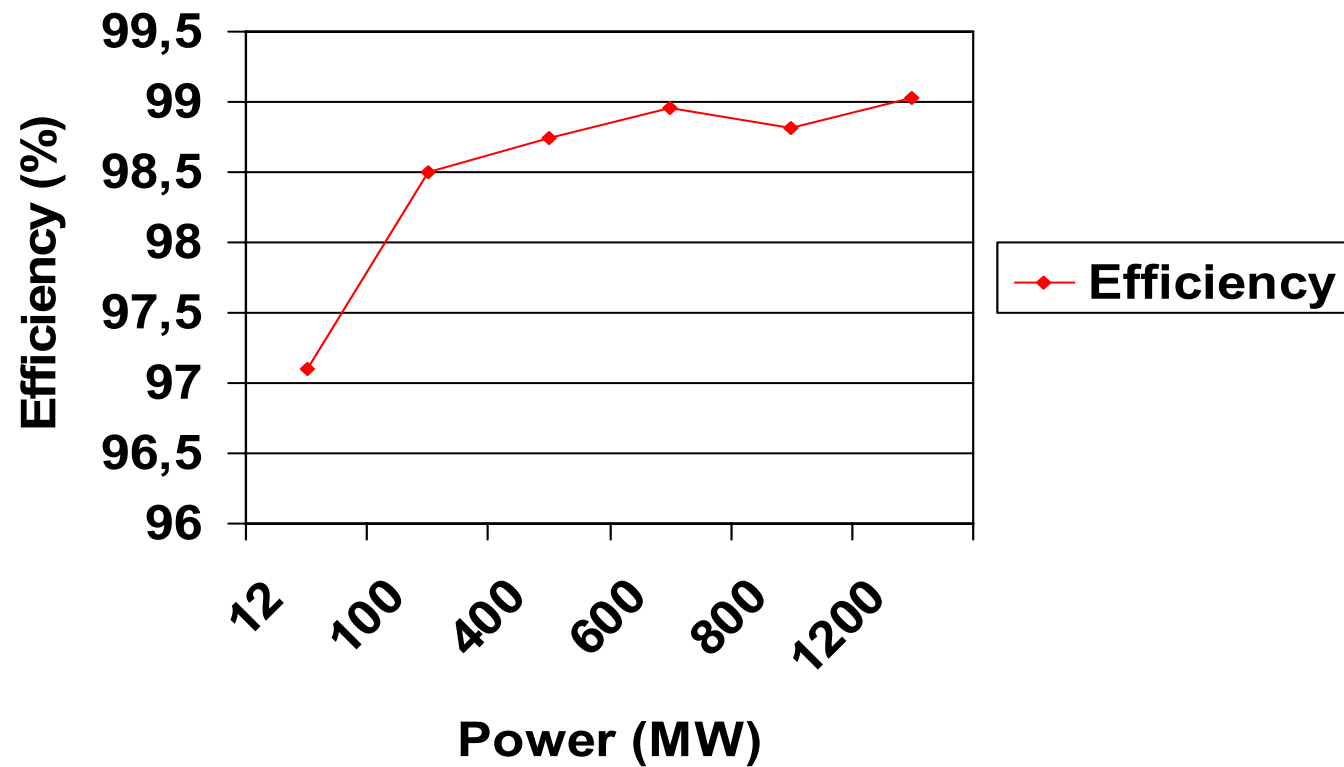
- Economies of scale will continue to dominate the future ...
- ... But not as much as in the past (in 40 years the economy of scale has been reduced by 30%)
- The efficiency of a plant (DG or CG) grows according to its rated power.

● Source: Willis, Distributed Power Generation.



- Please, do not forget the efficiency of Synchronous Generators

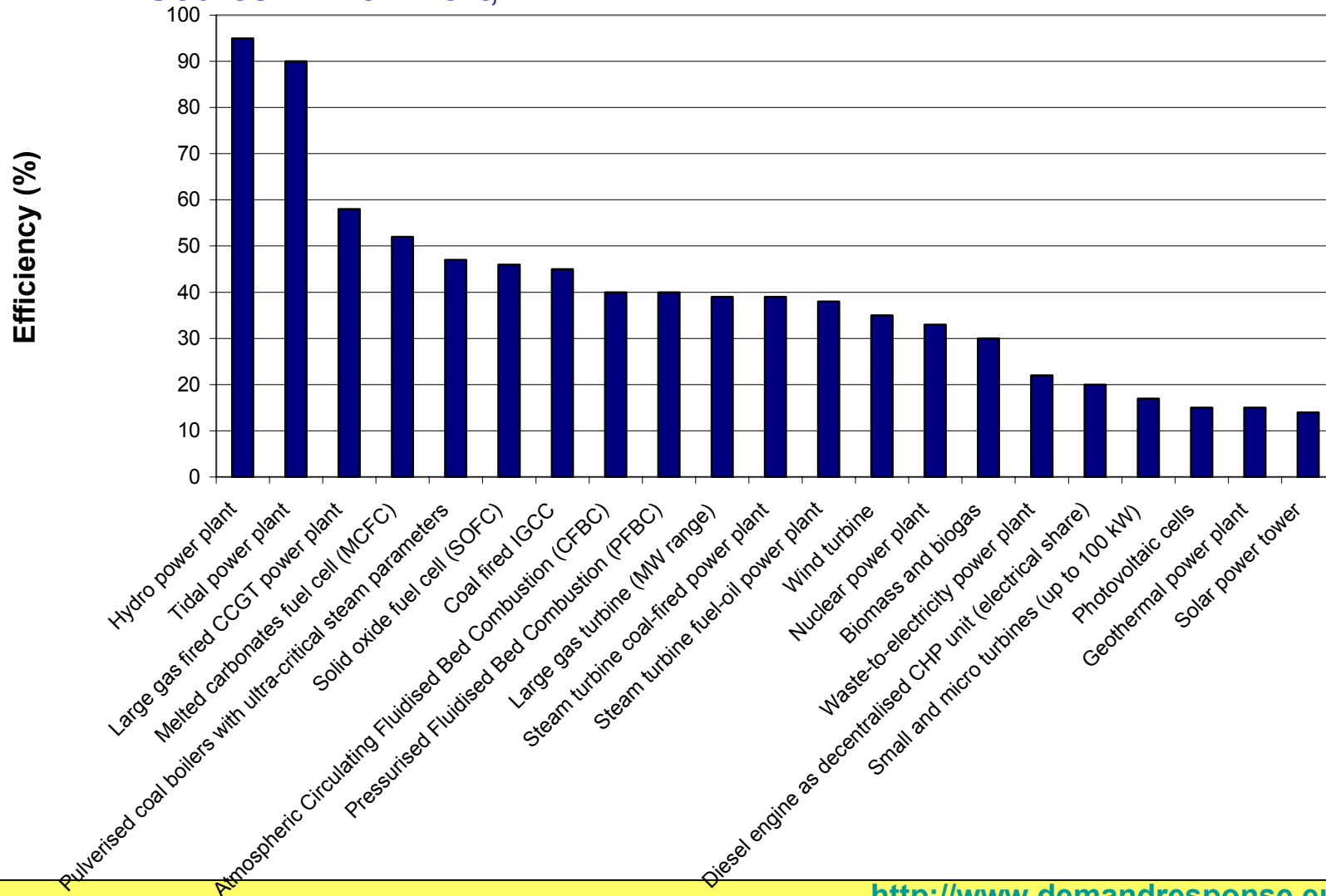
- Example: synchronous turbogenerators





## The efficiency of power plants according to different technologies: A review

Source: F. van Aart, KEMA



## ● Centralized vs. Distributed Generation (V)

### ● Reasons for the growth of DG:

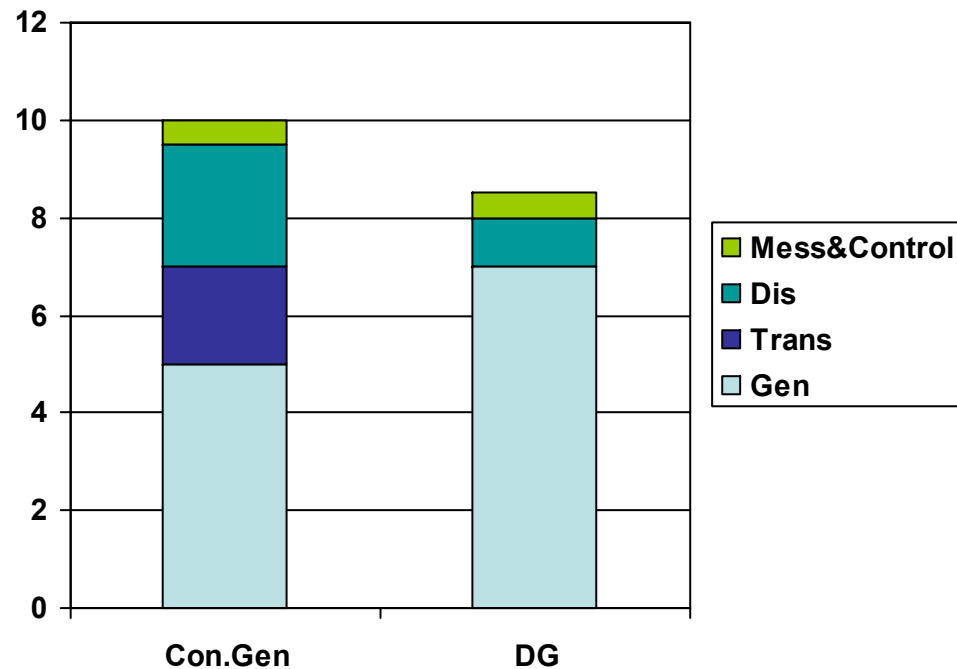
- Advances in energy conversion: eg. The improvement in gas turbines technologies
  - 30% efficiency in small turbines (good!)
  - 40% Cheng cycle turbines (very good!)
- Improved insulation and heat recovery unthinkable in the 60's.
- Changes in fuel cost vs. total cost
  - 1960/70: 80% of the total cost
  - 2000: 40-55% (increasing labor costs, emission control, ....)
- Automation, control, electronics: every time they require less human intervention
  - 1960: 60kW plant needed 2 or 3 people
  - 2000: no operator, full automation



## Block 6

## ● Transport and Distribution Costs

- DG is closer to the user, that is:
  - Decrease in investments (new resources)
  - Decreased labor and maintenance cost
  - Reduced losses / Tolls in T & D levels
- Example of average distribution and transmission losses for a customer with and without DG:



## Block 6

- **DG and the reliability of Power Systems**
- **Conventional systems (interruptions)**
  - 1960 standard: 8 hr / year of interruption of supply
  - 2000 standard: 2 hr / year (99.95%)
- **GD presents an opportunity for the reliability of supply: set our quality needs in a very interesting range of costs.**
  - From 95 to 98%
  - Up to 100% (this seems impossible with conventional generation). Why? If you use storage + GD + Conventional



## Block 6

## ● Additional advantages and problems of DG

### ● Advantages:

- ✓ Modular: DG plants are manufactured in series (conventional are "hand made"). It simplifies the engineering and installation
- ✓ Environmental clean technologies (mostly) without a complicated structure of T & D

### ● Problems:

- ✗ Ownership and operation: who is responsible for the plant? It is difficult for the owner
- ✗ Fuel supply: it is sometimes not easy to deliver fuel gas system. Is there? The gas supply (transport) may increase up to 25% costs.
- ✗ Non validated technologies: In general a new technologies pose a risk (... perhaps an opportunity).



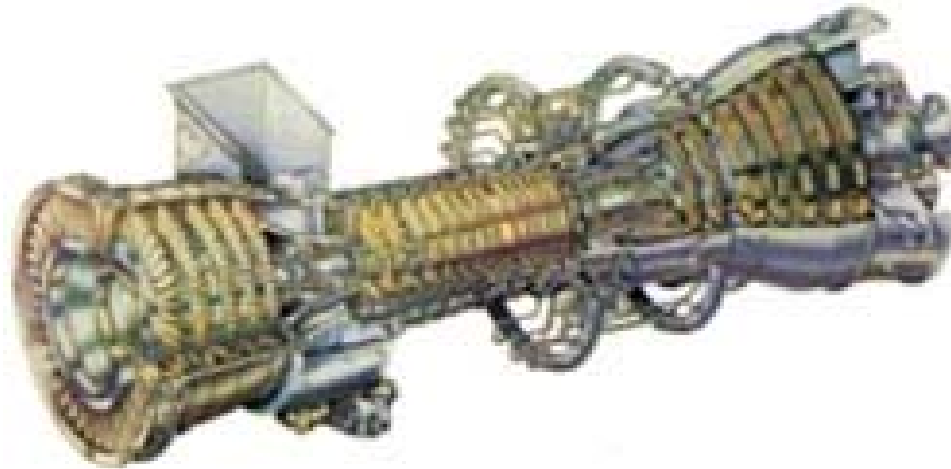
## ● DG Technologies

| Technology      | Available | Emergent |
|-----------------|-----------|----------|
| Microturbine    | ✓         | ✓        |
| Gas Turbine     | ✓         |          |
| Recip. Engine   | ✓         |          |
| Stirling Engine | ≈         | ✓        |
| Fuel Cells      | ✓         | ✓        |
| Photovoltaics   | ✓         |          |
| Wind            | ✓         |          |
| Hybrid Systems  | ≈         | ✓        |



## Block 6

- **Gas Turbines (I)**



- **Advantage: Footprint ( $\text{m}^2/\text{kW}$ )**
- **Range of use**
  - Microturbines: up to hundreds of kW
  - Miniturbines: up to 10 MW
  - Utility: 10MW to 1200MW

## ● Gas turbines (II)

- They have been used for electric generation since 50's (USA) and 70's (France). For example in Railways.
- Problem: high fuel costs (turbines adapted from aircrafts developments)



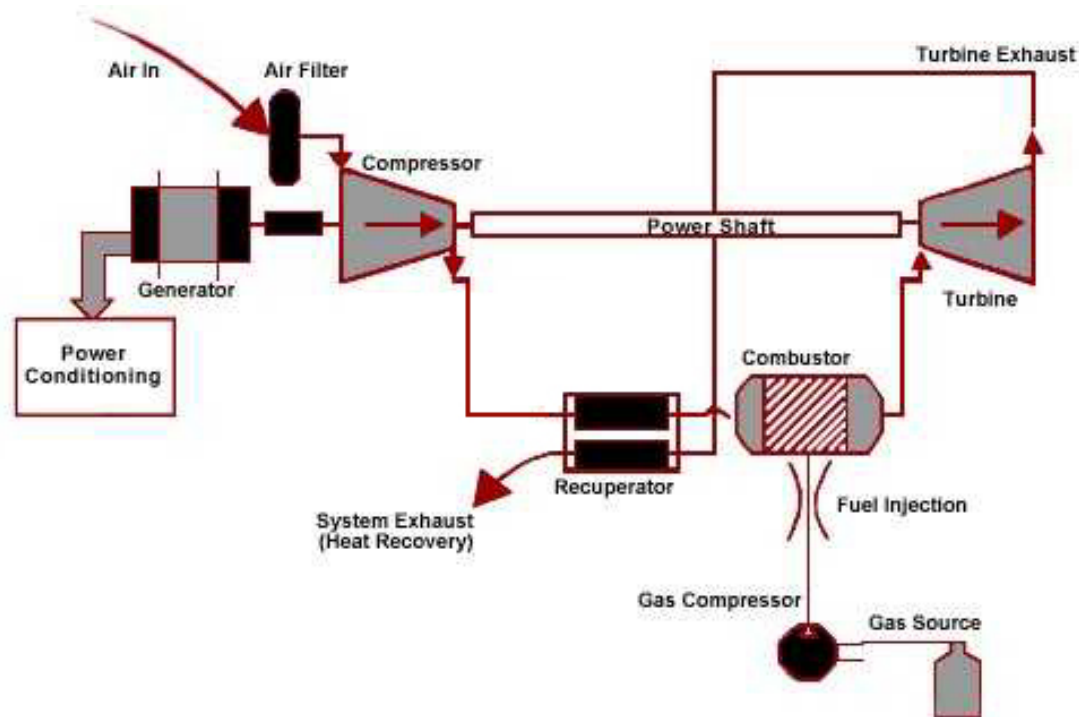


## Block 6

## ● Microturbines

- There is a limited commercial availability.
- Power range: 25-500kW
- Fuel: NG, H<sub>2</sub>, propane, diesel, ...
- Efficiency: 20-30%
- Emissions: low (9-50 ppm NO<sub>x</sub>)
- Other options: cogeneration (hot water 50-80C)

● Figure source: CEC & EPRI, USA



## ● Gas turbines (II): generalities

- Manufacturers: Alstom, General Electric (PS), Siemens, Rolls-Royce, Capstone, Bowman.
- Can reach 45% efficiency (at full load)
  - Figure source: Willis, "Distributed Power Generation"

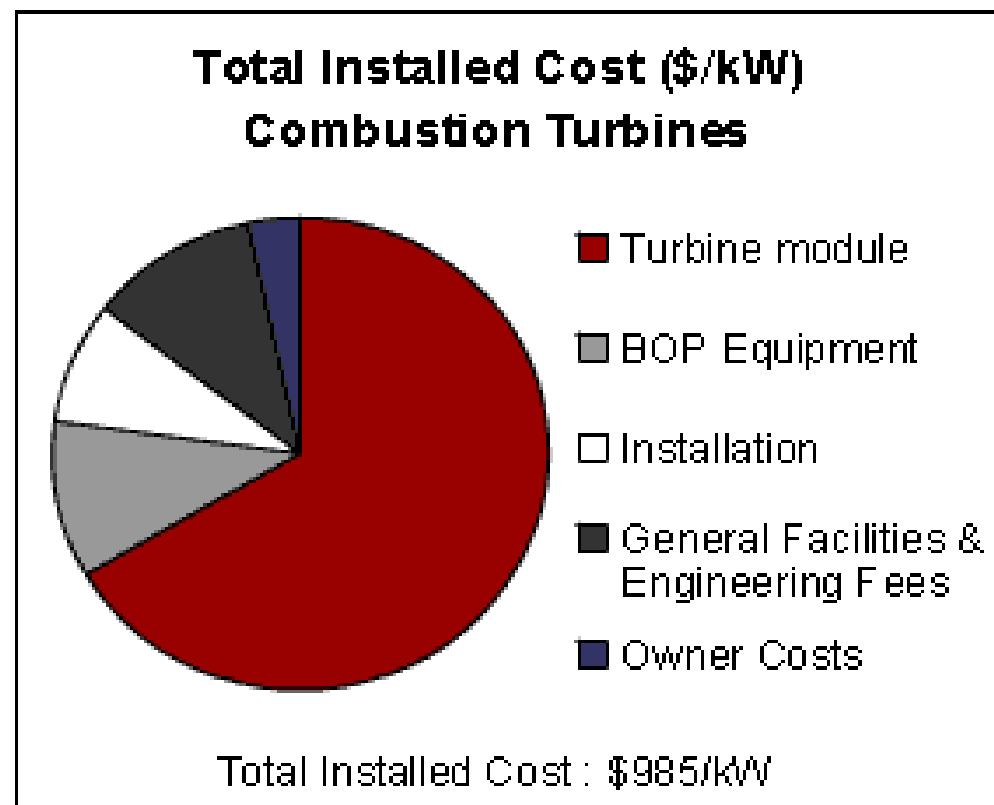
| Characteristic                      | Micro              | Mini             | Utility            |
|-------------------------------------|--------------------|------------------|--------------------|
| Available range – kVA               | 20 – 500           | 650 – 10,000     | 12,500 – 265,000   |
| About the size of . .               | a refrigerator     | a large truck    | a building         |
| Original design based on . . .      | bus, truck engines | aircraft engines | utility needs      |
| Most typical fuels are . . .        | nat. gas, diesel   | nat. gas, diesel | nat. gas, fuel oil |
| Makes about as much noise as        | a car at 40 mph    | 3-4 leaf blowers | a jet plane        |
| Out of service once every . . .     | Two years          | Eight months     | Year and a half    |
| Turbine generator usually is        | single-shaft       | two-shaft        | two or three shaft |
| Turbine spins at about              | 70,000 RPM         | 15,000 RPM       | 1,800 RPM          |
| Generator type used is              | DC with AC conv.   | AC sync.         | AC sync.           |
| Generator turns at about            | 70,000 RPM         | 3,600 RPM        | 1,800 RPM          |
| Turbine & generator run at          | Variable speed     | Constant speed   | Constant speed     |
| Best fuel efficiency is about . . . | 32%                | 30%              | 37%                |
| Can be bought and installed in      | a week             | two months       | a year or two      |
| Typical cost/kW is . . .            | \$700/kW           | \$450/kW         | \$300/kW           |



## Block 6

● **Gas turbines (III): costs**

- Initial costs (700 to 1110 \$/kW): There are external costs that increase the price of 30-50% turbine
- Maintenance: 5000-8000 hr/operation ( $\approx$  ICE)
- Figure source: CEC, USA



- BOP: heat exchangers, pumps, condensers,...

## ● Gas turbines: advantages and drawbacks

### ● Advantages:

- Utilization of waste heat
- Network servicing
- Great power to weight ratio
- Reliable
- Lower emissions
- They can use residual fuels
- Starting time: 2 to 5 minutes (fast ► peaking units in PS)

### ● Disadvantages

- Low efficiency at part load (performance may be reduced by 25% at ½ load).
- Electrical performance is low without heat recovery
- Sensitive to environmental conditions (high temperature and altitude)
- Noise (> 60dB)



### ● Internal combustion engines (ICE)

- Are the most common and more mature DG technology
- They are available in various sizes (5kW to 10MW)
- Fuels: gasoline, fuel oil, natural gas, diesel, biofuels...
- Efficiency: 25 to 45% (full load)
- Represent 80-90% of GD
- Start times of 30s to 15min



## Block 6

## Types of Int. Combustion Engines (II)

- High-speed units: more similar to those used in automobile (1200 to 3600 rpm).
  - More power (worst performance for DG purposes)
  - Cheaper
- Units of medium speed (275 to 1000 rpm)
  - Railway units / small boats
  - More expensive, better efficiency
- Low-speed units (58 to 275 rpm)
  - Use low-quality residual fuels
  - Highest level of environmental emissions

| PeI (kW) | El.effcy (%) | Pther (kW) | Ther-effcy (%) |
|----------|--------------|------------|----------------|
| 22       | 28,4         | 45,5       | 58,8           |
| 100      | 32,8         | 161        | 52,8           |
| 1030     | 37,4         | 1395       | 50,6           |
| 3884     | 41           | 4312       | 45,6           |



## ● An alternative classification of ICE (II)

- Simple cycle motors: that do not have cogeneration capacity (start times <1 min), ie backup generators or generators peak.
- CHP: harness the waste heat to generate steam (<50% of thermal energy, ie worse than any turbine) or hot water
- Energy flows in ICE
  - 30% mechanical energy
  - 30% coolant
  - 15% in the flue gas
  - Rest in losses: radiation, gases, ....

| ICE engine  | Efficiency range (%) |
|-------------|----------------------|
| Natural Gas | 28-42%               |
| Diesel      | 30-50%               |
| CHP         | 80-85%               |



### ● ICE costs (an approximation)

- Installation costs (they increase between 50-100% over the price of the engine, ie 700 to 1200 \$/kW)
- Maintenance: each 700-1000hr (0.005 to 0.01 \$ / kWh).

| Rated Power<br>(kW) | Fuel     | Capital cost<br>(€/kW) | O&M<br>(€/kW) |
|---------------------|----------|------------------------|---------------|
| 50                  | Gasoline | 350                    | 40            |
| 250                 | Diesel   | 436                    | 16            |
| 1000                | Diesel   | 352                    | 1,4           |
| 1100                | Nat. Gas | 438                    | 2,0           |





## ● ICE engines. Resume

| Advantages                    | Drawbacks            |
|-------------------------------|----------------------|
| Low capital costs             | Emissions            |
| Good efficiency in conversion | Noise (>70dB)        |
| Fast start                    | Frequent maintenance |
| Fuel flexibility              |                      |
| Reliability                   |                      |



## ● **Manufacturers**

- DTE energy technologies
- Power Plus Technologies GmbH
- Cummins
- Generac Power Systems
- Honda Power Equipment
- Kohler Generators



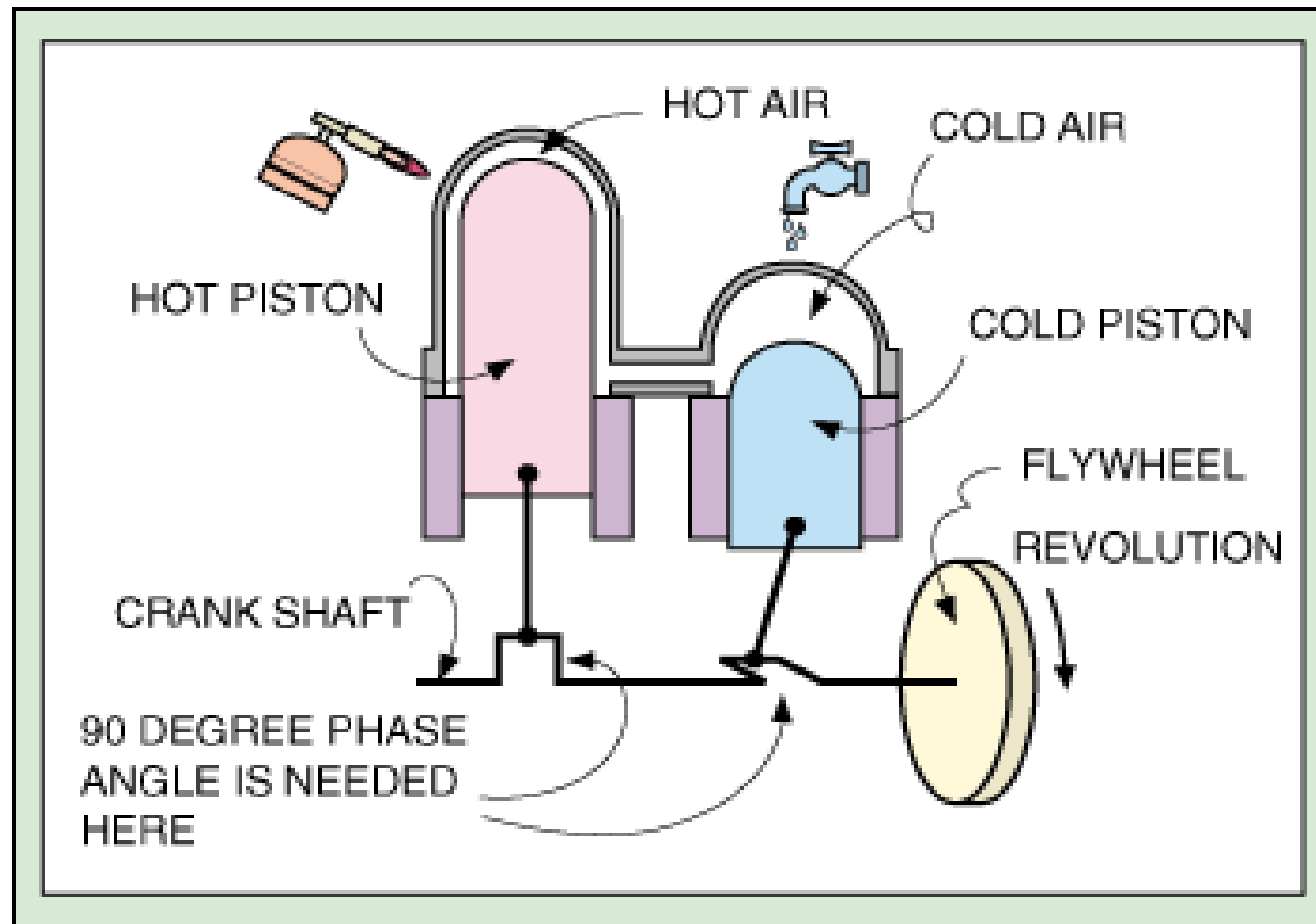
## ● Stirling engines (I)

- External combustion (sealed system)
- Working fluid: He, H
- Low power units: 1-25kW
- Available 2005, 2010, 2015?
- 12-30% efficiency
- Low emissions



## ● Stirling engines (II)

- Like the well known steam engine, but the heat source is external.



## ● Commercial and pilot developments

- SunCatcher (25kW). Source: Stirling Energy Systems
- Sandia Lab: evaluating 5 SunCatcher since 2005
- Maricopa Solar Plant, Arizona, USA (1.5MW up to 60 units)



### ● Stirling engines (III): other applications

- With a 100kW solar concentrator at the University of California (Boeing)
- Cooling (to-193C missile microprocessor or superconducting)
- Vehicles (US research)



## ● Manufacturers

- Stirling Energy Systems (USA): 25kW
- Stirling Biopower (USA): 43kW (The power unit)
- Stirling Systems AG (Europe):
  - Stirling Energy Module (SEM), 1.2 kW



## ● Stirling Engines (IV). Conclusions

| Advantages                                                            | Drawbacks                                  |
|-----------------------------------------------------------------------|--------------------------------------------|
| Without wear, vibrations                                              | High costs (4000 a 10000€/kW)              |
| Low emission                                                          | Low efficiency 15-20% (30% in the future?) |
| Simplicity                                                            | Power output control: heavy and difficult. |
| Low quality fuels (waste gas and fuels)                               |                                            |
| Lifetime (up to 6 year in continuous use). Long maintenance intervals |                                            |





## ● Fuel-cells (I)

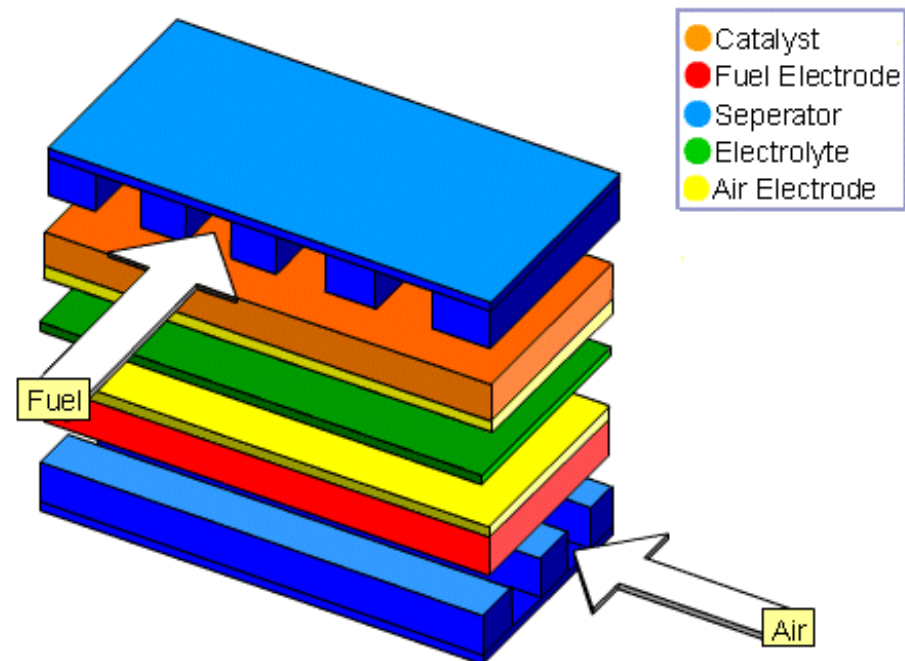
- It isn't a new concept (100 year old, it was invented in 19th century)
- First applications (60's): Apolo & Geminis spacecrafts
- The future is bright but ..., just never get ?
  - The difficulty of making them cost effective



## Fuel-cells (II)

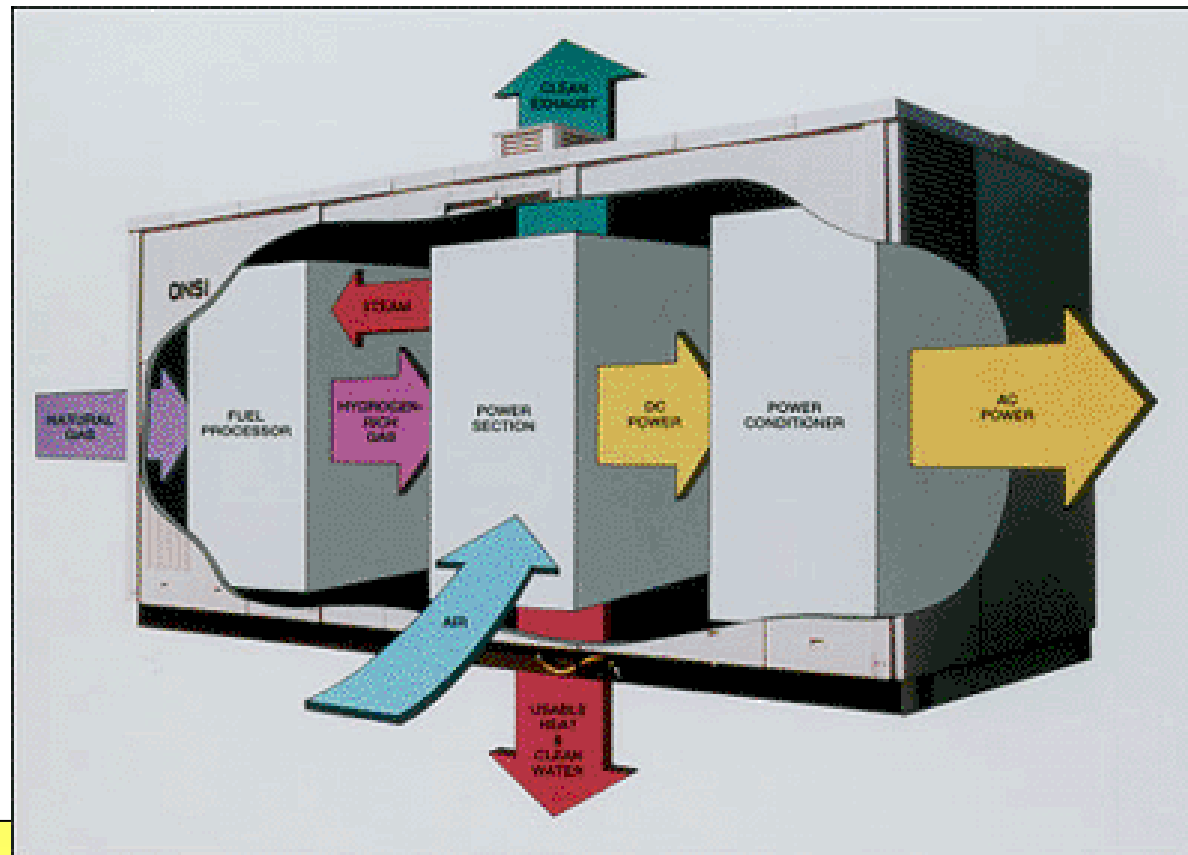
- Principle: the reverse of an electrolysis process
- It works like a battery (an electrochemical reaction without combustion)
- The reactants are gases (hydrogen / air)
- The fuel is preprocessed to obtain  $H_2$

Generic Fuel Cell



## ● Fuel-cells (III): tipos

- PAFC (phosphoric acid), PEM (proton exchange membrane); AFC (alkaline); MCFC (Molten carbonate); SOFC (Solid Oxide)
- Efficiency: del 35-55%; Power: 1 to 250kW
- Basically (in PS): Pilot projects



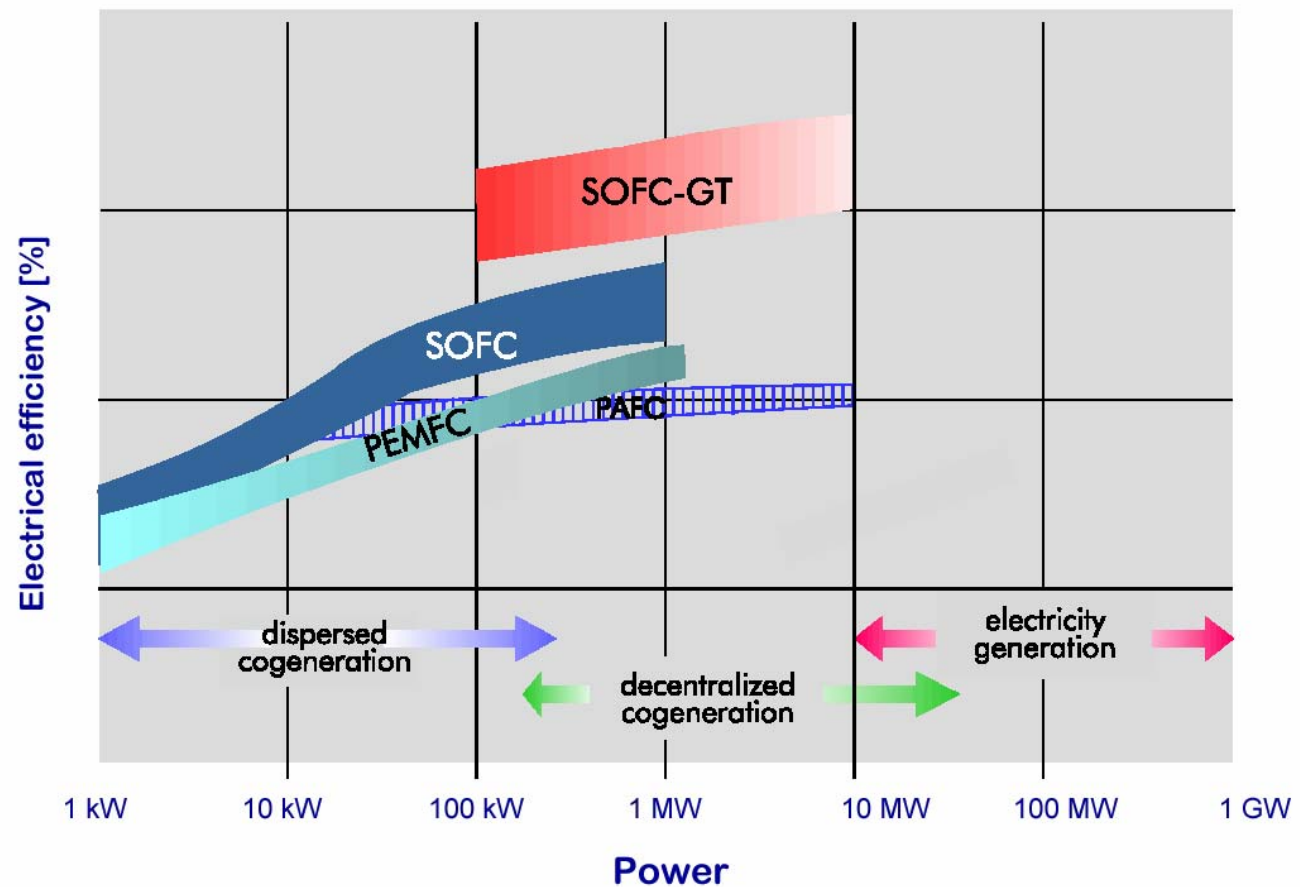
## ● Fuel-cells (IV): characteristics

| Tipo               | PEMFC                   | AFC                   | PAFC     | MCFC     | SOFC               |
|--------------------|-------------------------|-----------------------|----------|----------|--------------------|
| P(kW)              | 1-10 (R)/<br>75-250 (C) | 25-100                | 200      | 250      | 3-10 R/<br>250 (C) |
| T <sup>a</sup> (C) | 80-100                  | 80-100                | 200-400  | 600-700  | 600-1100           |
| η (%)              | 35-50                   | 50-60                 | 40       | 45-65    | 50-70              |
| Availability       | First dev.              | Low                   | Low      | Low      | First dev.         |
| Aplicaciones       | Vehicles,<br>R, C, DG   | Vehicles,<br>R, C; DG | R, C, DG | R, C, DG | R, C, DG           |

● R: Residential; C: Commercial; DG. Dist. Gen.



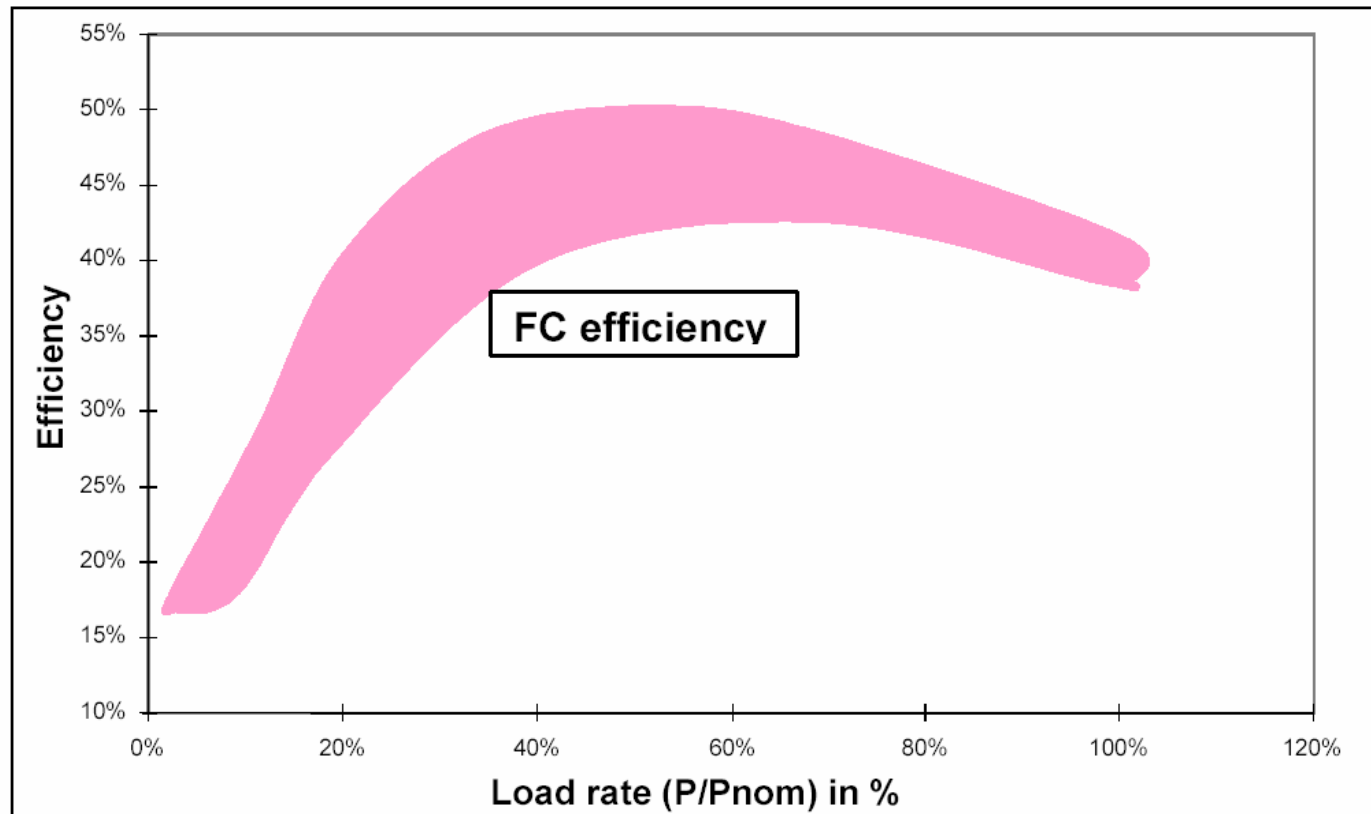
- **Fuel cells: Efficiency and range of use for technology**  
(Source: Alstom)



## Block 6

- **Fuel cells: efficiency as a function of the load**  
(interesting for some application!)

● Source: ALSTOM



## ● Fuel cell (V): Manufacturers

- PEMFC: Teledyne, Plug Power, General Motors
  - Wide range of applications (portable, automotive, residential, commercial, light industrial)
  - ► low temperature quick start
  - Maturity of technology: 2010?
- PAFC: UTC Fuel Cells
- MCFC: Fuel Cell Energy
  - Some commercially available
- AFC: Apollo Energy Systems
- SOFC: Ceramic Fuel Cells, ZTEK Corporation
  - Wide range: residential, commercial and industrial facilities (5-250kW)
  - High temperature (1000C) ► slow start (5-10h at times)
  - Maturity of technology: 2015?



## ● Fuel cells (V): Conclusions

| Advantages                            | Drawbacks                                               |
|---------------------------------------|---------------------------------------------------------|
| High lifetime (PAFC & SOFC > 20000hr) | Low lifetime (PEMFC, MCFC, sometimes < 3000h)           |
| Noiseless                             | Costs                                                   |
| Low emissions                         | Experience: Very low except in some technologies (PAFC) |

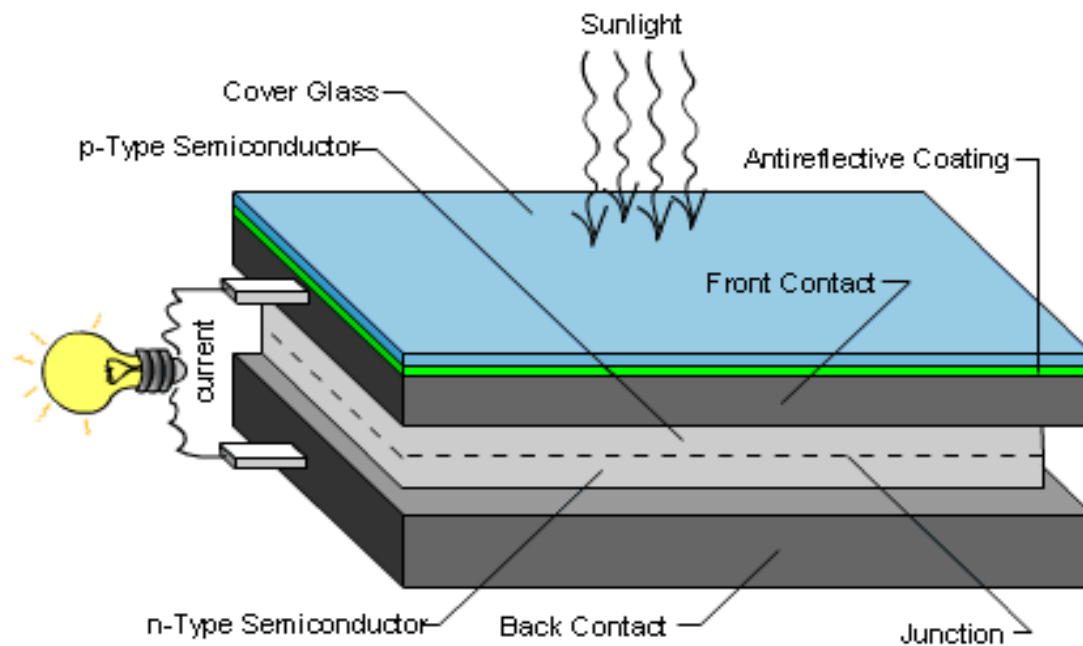




## Block 6

## ● Photovoltaics, PV (I)

- Commercially available
- Power Range: 1kW to 100kW
- Efficiency: 5-15% (theoretically up to 30%)
- They have no emissions
- Advanced systems under development (20-30% efficiency)



## ● Photovoltaics (II)

● Future??? Subsidies?

| Advantages                            | Drawbacks                                                                                                                   |
|---------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|
| Low emissions (but they have someone) | Maintenance (cleaning of arrays)                                                                                            |
| Simplicity                            | Capital Cost: 4000€/kW                                                                                                      |
| Lifetime: 20, 40 years                | Another costs: control, structures, batteries, energy conversion (BOS: balance of system): from 6000 to 10000€/kW installed |



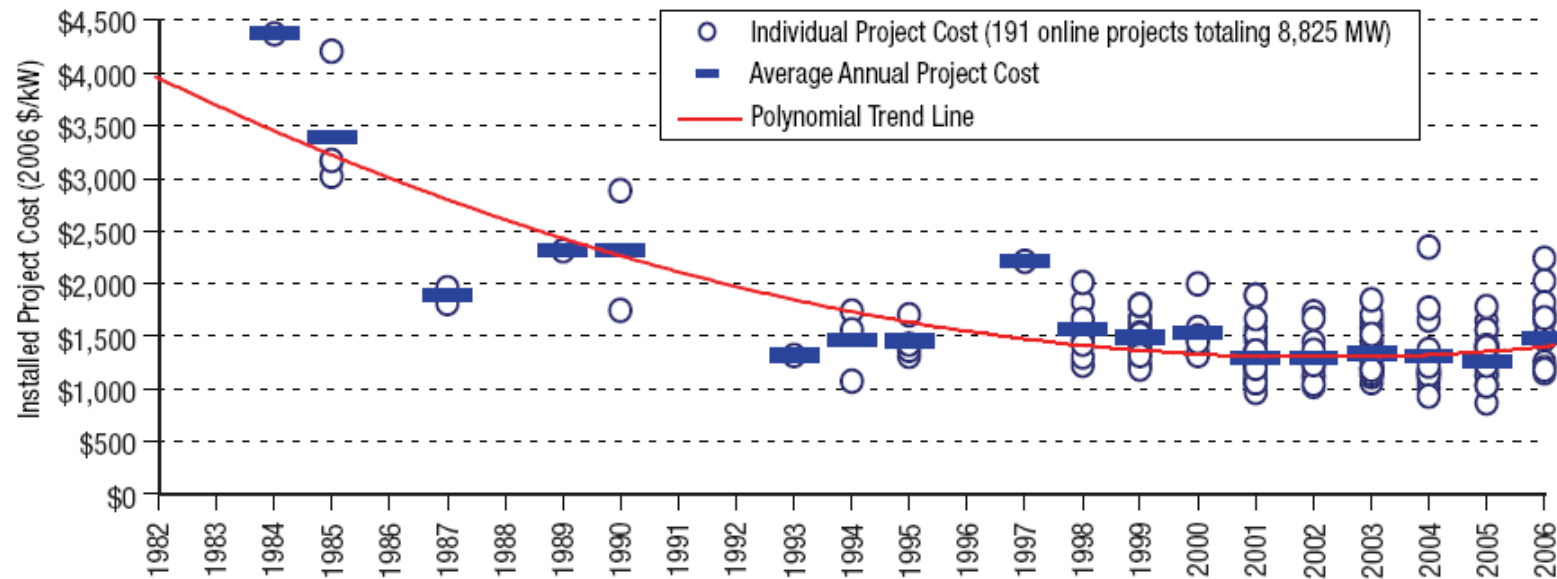
## ● Wind farms (I)

- Probably the best renewable energy
- Powers: some kW to 5MW
- Efficiency: 20-40%
- Various sizes, systems, speeds, ....



## ● Cost reduction in new projects

● Source: Lawrence Berkeley Nat. Lab, USA & US DoE reports



## Block 6

 **Wind farms (II)**

-  Large wind turbines are on the threshold of profitability.  
Installation cost (avg) 1500 €/kW
-  Production Cost: 3 to 6 c€ / kWh

| Advantages                     | Drawbacks                                |
|--------------------------------|------------------------------------------|
| Low emissions and energy costs | The output is essentially uncontrollable |
| Minimal use of land            | Site (access)                            |
|                                | Visual impact                            |
|                                | Bird mortality                           |

