Introduction To DG

Background Information for the Distributed Generation Regulation Development Workgroup

Definition of Distributed Generation

"Distributed Generation (DG) refers to electricity generation technologies that are relatively small in size and can be deployed close to customers within the distribution system."

Source: Delaware Public Service Commission (PSC) Electric Reliability White Paper

Types of Electric Resources

Central

Large Generation
Coal-Steam
Nuclear-Steam
Hydroelectric

Modular Generation
Combined-Cycle
Combustion Turbine

Distributed

Fossil-based

Commercial & Advanced
IC Engines
Gas Turbines

Emerging
Microturbines
Fuel Cells

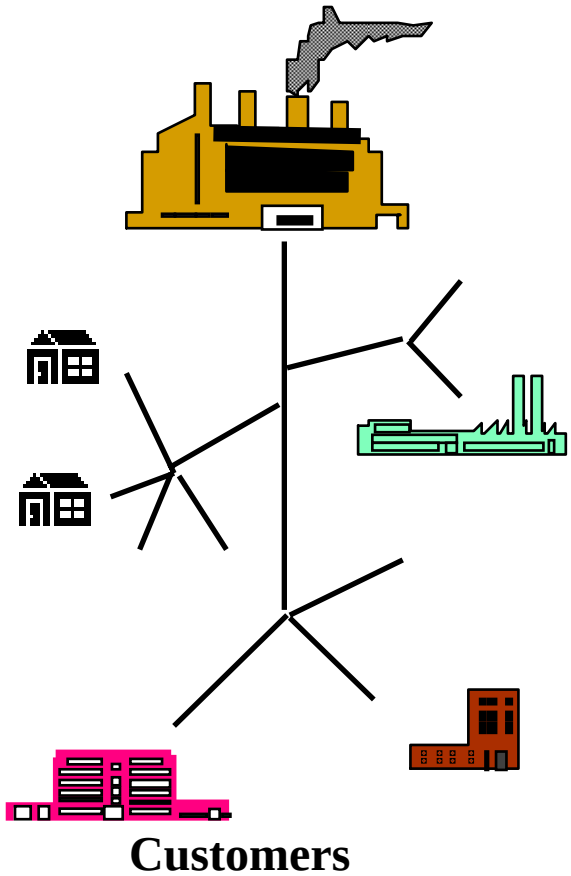
Renewable Gen.

Generation
PV
Wind

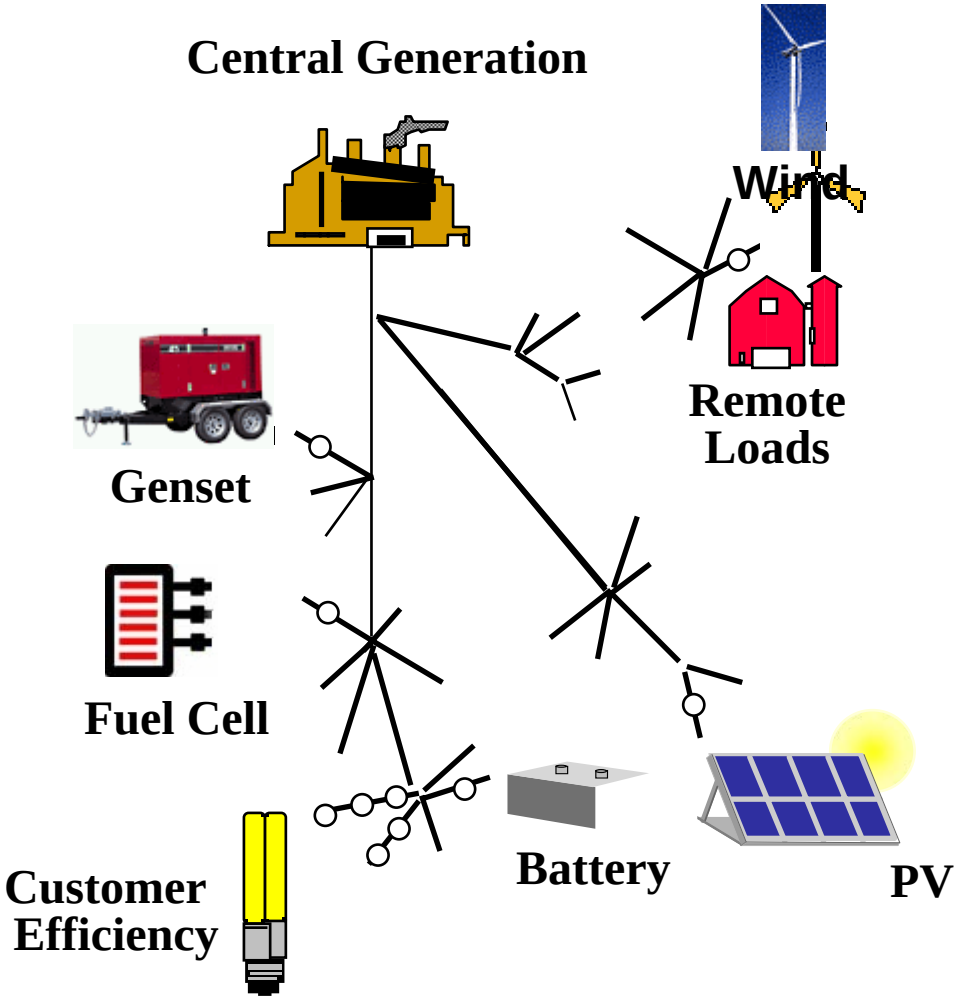
Non-Generation
Batteries
Other Storage
DSM

Source: CADER 1998.

Today's Central Utility



Tomorrow's Distributed Utility?



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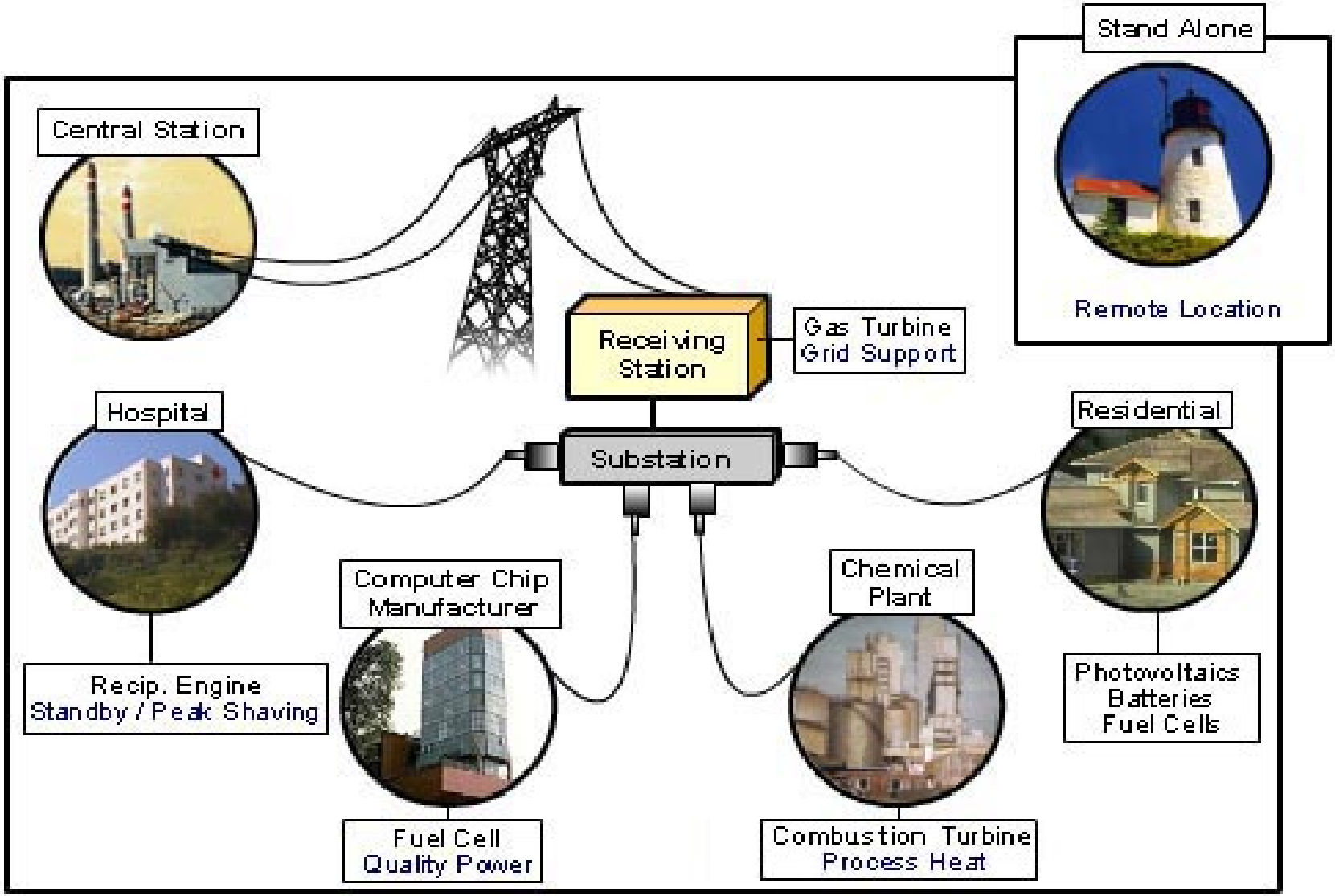
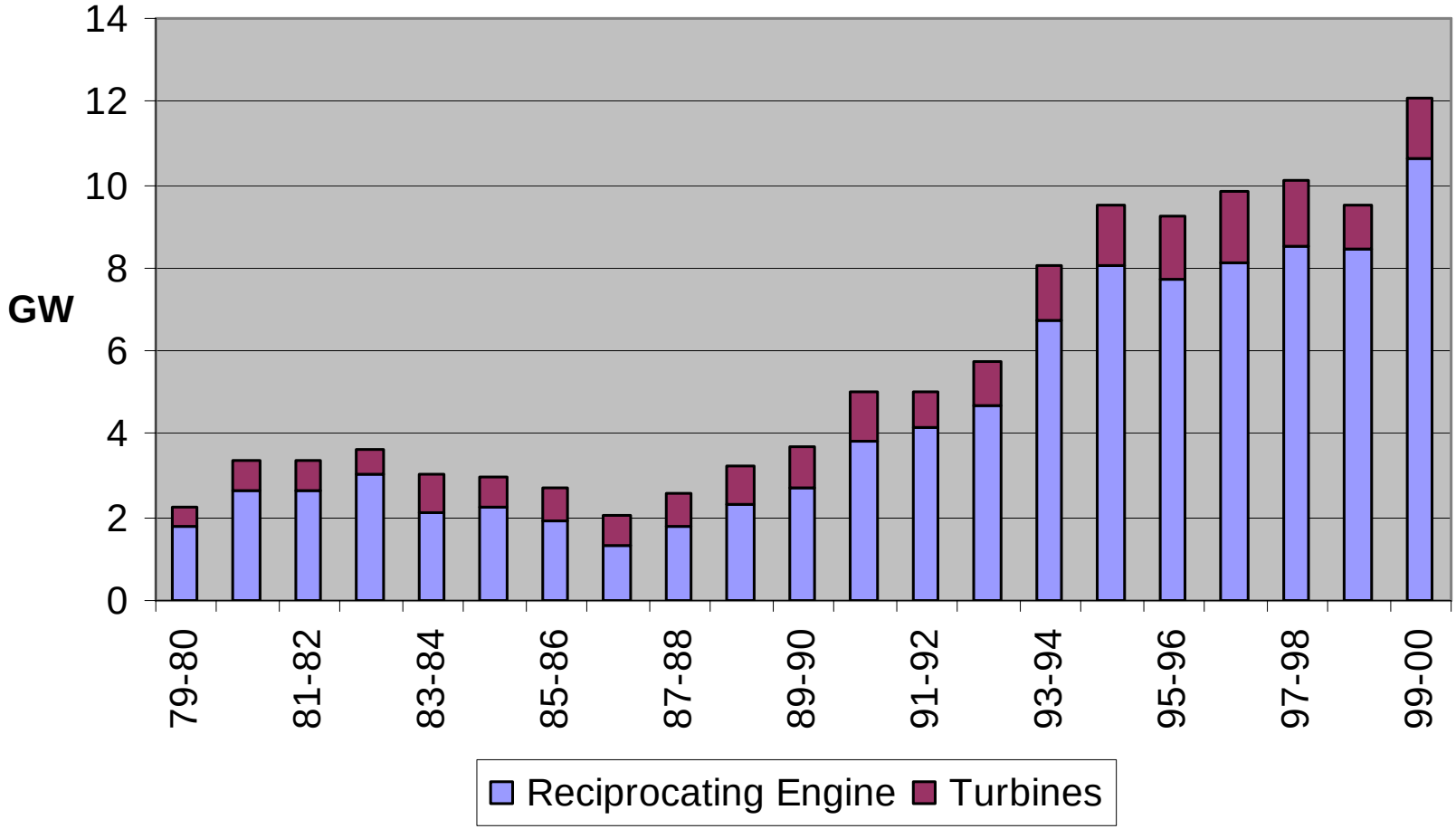
DG Illustration (source: California Energy Commission)



Global Distributed Generation Market Trend:

1 to 10 MW Reciprocating Engines and Turbines

Annual Sales (GW)



Source: Diesel & Gas Turbine Worldwide

Factors Driving Trend Toward Distributed Generation

- Reduction of overall costs to electricity consumers
- Need for increased generation capacity
- Need for improved reliability
- Need for increased security
- Need to respond to demand peaks
- Power industry deregulation/restructuring
- Increasing environmental regulations on central power plants

Main Technologies Used For DG

- Reciprocating internal combustion (IC) engines
- Combustion turbines
- Microturbines
- Fuel cells
- Wind turbines
- Photovoltaic panels

Reciprocating IC Engines

- Size range: 5 KW to 7 MW
- Types
  - High speed (1200-3600 rpm): derived from automobile & truck engines
  - Medium speed (275-1000rpm): derived from locomotive and small marine engines
  - Low speed (58-275 rpm): derived from large ship propulsion engines

Reciprocating IC Engines: Fuels Used

- Spark ignition:
  - Gasoline
  - Gas [natural gas, propane (LPG), landfill gas, digester gas, process gas]

- Compression ignition:
  - Diesel (No. 2 fuel oil or distillate oil)
  - Residual oil
  - Dual fuel (natural gas plus diesel)

Diesel 60 KW Genset

Enclosed Diesel 60 KW Genset

6 KW Propane Genset

Combustion Turbines

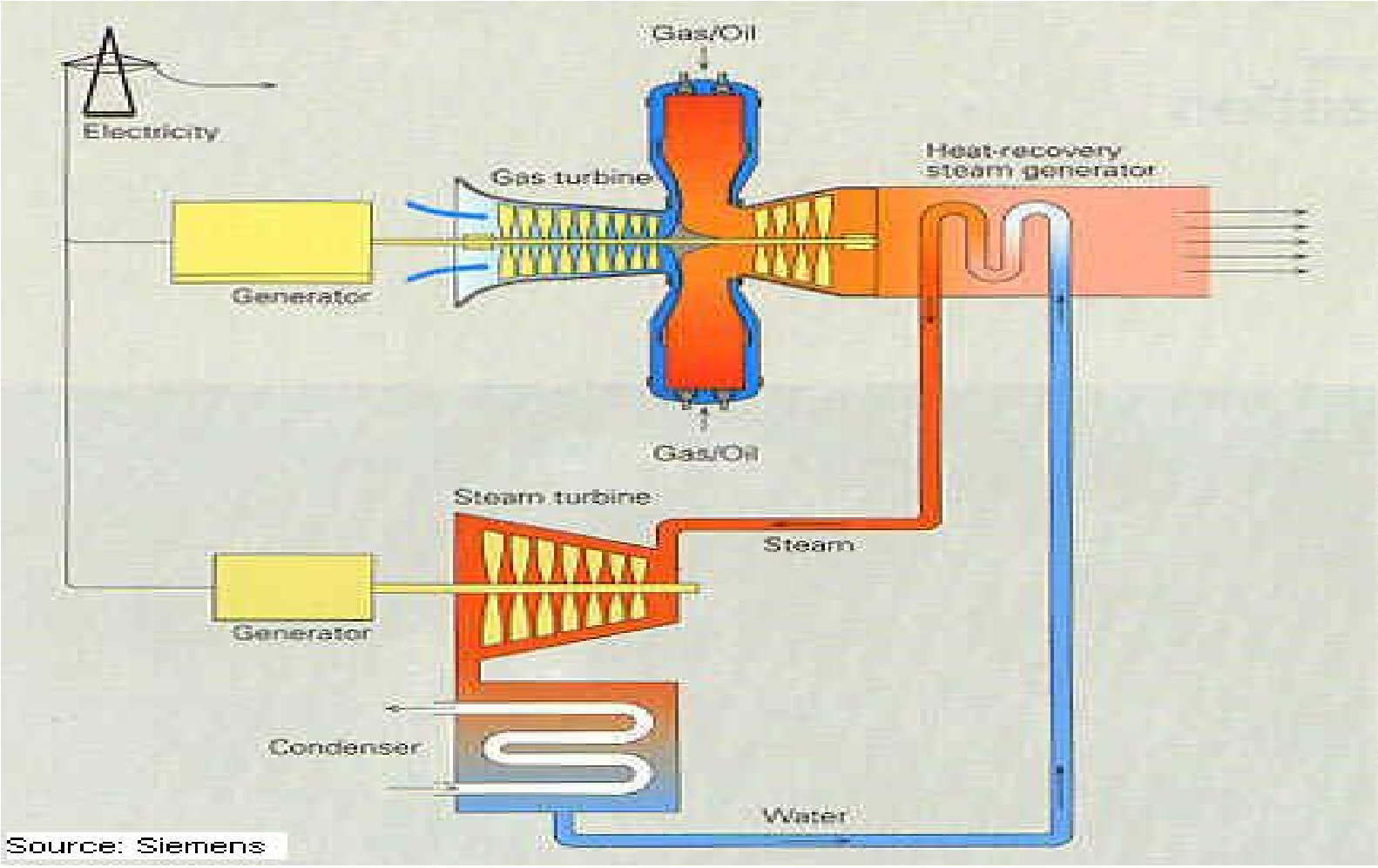
- Non-reciprocating internal combustion engines
- Size range: 500 KW to 250 MW
- Smaller versions used for DG, larger for central power plants
- Fuels: natural gas, oil, or combination
- Startup time: 2 to 5 minutes
- Can be Simple Cycle (single unit) or Combined Cycle (gas turbine combined with a steam turbine)

Combined Cycle Combustion Turbine

- Uses combination of gas and steam turbines to generate electricity with higher conversion efficiencies and lower emissions.

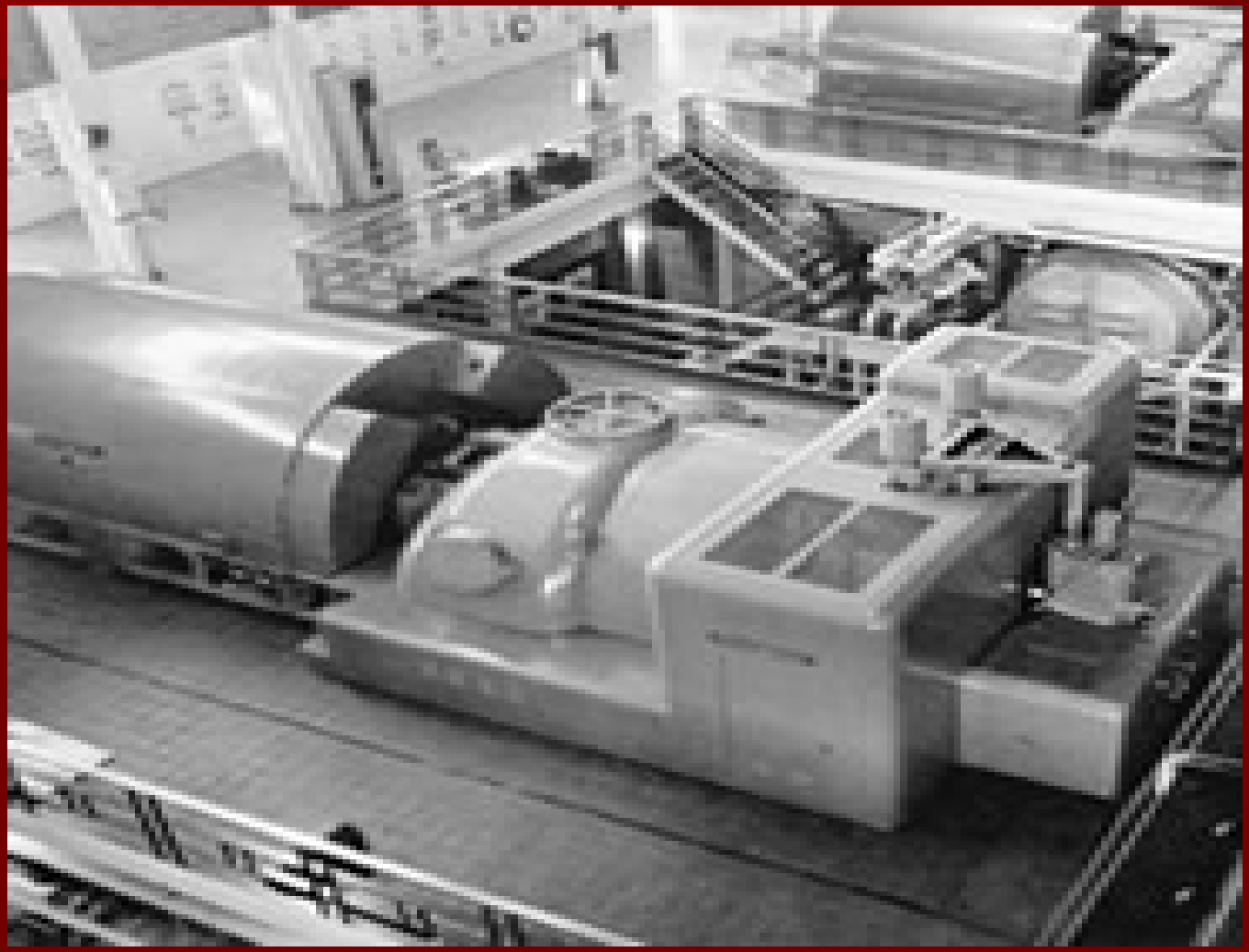
  How it works: The Gas turbine generates electricity. Waste heat from the gas turbine exhaust is routed to a waste heat boiler to produce steam, which in turn powers a steam turbine generator for production of **additional electricity**.
- Distinguished from **Combined Heat and Power**, in which steam from the waste heat is used for process or space heating, rather than to produce more electricity.

Schematic of Combined Cycle Gas Turbine



Consists of one gas turbine and one steam turbine. The gas turbine exhaust gas is routed to a heat exchanger, the heat-recovery steam generator, to raise superheated steam for the turbine without any additional fuel consumption.

Combustion Turbine



(2) 40 MW Combustion Turbines – Gas or Oil-Fired

Microturbines

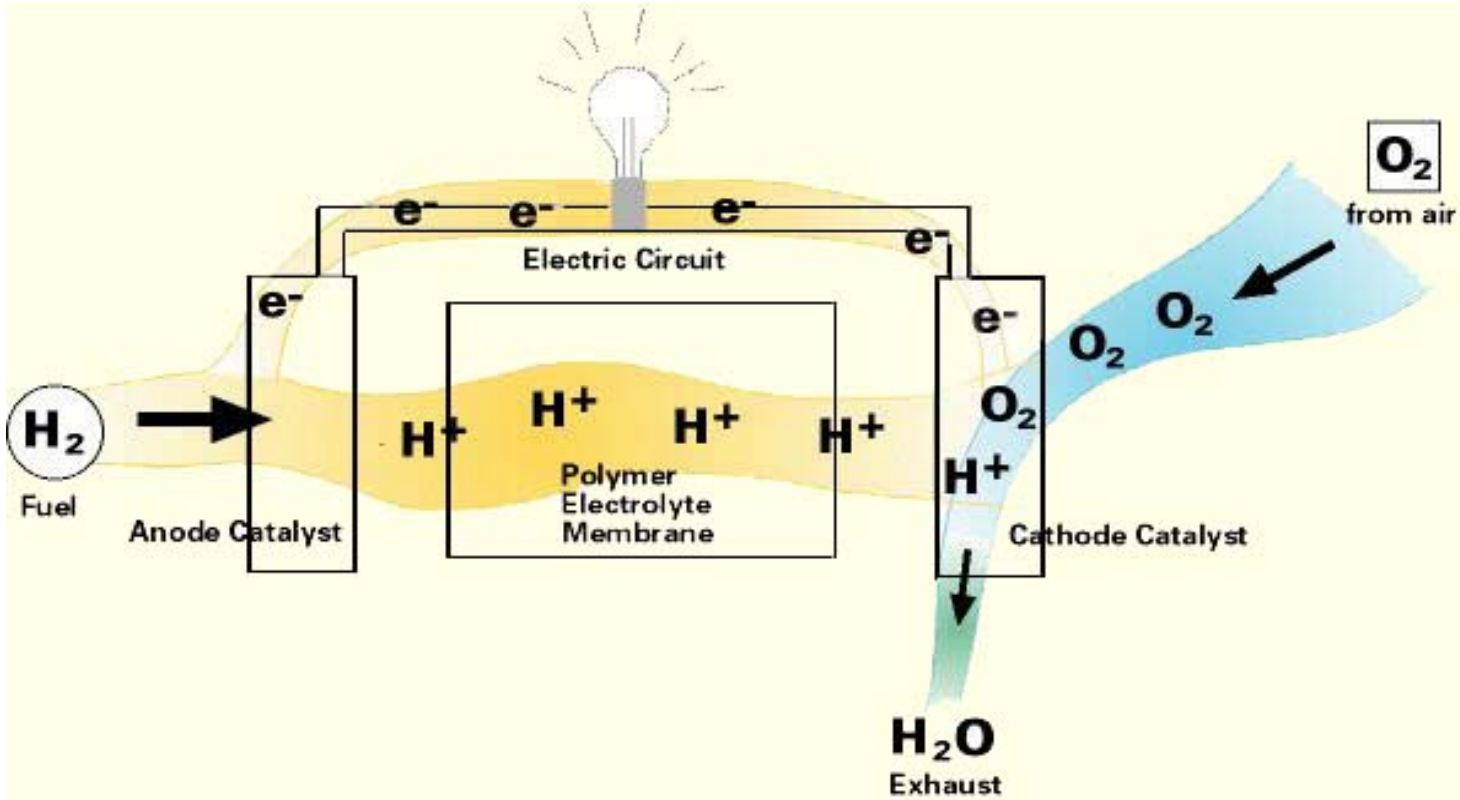
- What is a microturbine?
  - Essentially a packaged automotive turbocharger combined with elements of aircraft auxiliary power systems
- Size Range: 25 KW to 500 KW
- Fuels: natural gas, waste gases, oil

60 KW Microturbine

Fuel Cells

- Contain electrodes and an electrolyte
- Convert hydrogen and oxygen (chemical energy) into electricity and heat
- Operate like batteries that recharge while being used
- Recharge using hydrogen-containing fuel rather than electricity
- Major difference between main types of fuel cells used for DG is the electrolyte used: *phosphoric acid, molten carbonate, solid oxide, proton exchange membrane*

Operation of Fuel Cell



Hydrogen fuel is fed into the "anode" of the fuel cell. Oxygen (or air) enters the fuel cell through the cathode. Encouraged by a catalyst, the hydrogen atom splits into a proton and an electron, which take different paths to the cathode. The proton passes through the electrolyte. The electrons create a separate current that can be utilized before they return to the cathode, to be reunited with the hydrogen and oxygen in a molecule of water.

Fuel Cells

- Size Range: 1 KW to 10 MW
- Fuels: natural gas, waste gas, propane, hydrogen, fuel oil
- Emissions: nearly zero, and usually carbon dioxide

100 KW Phosphoric Acid Fuel Cell

250 KW Molten Carbonate Fuel Cell

100 KW Solid Oxide Fuel Cell

250 KW Proton Exchange Membrane Fuel Cell (Natural Gas-Fueled)

Wind Turbines

- Size range: a few KW to 5 MW
- Zero emissions
- Difficult to site:
  - Wind characteristics must be optimal
  - Area must be free of obstacles such as trees, hills and buildings
  - Towers need significant height to take advantage of greatest wind velocity
  - Generation varies with wind velocity

1.5 MW Wind Turbines

Photovoltaic (Solar) Panels

- Convert sunlight directly into electricity
- No moving parts
- Zero emissions
- Size range: 1 KW to 100 KW
- High initial expense
- Need a large surface area
- Generation varies with intensity of sunlight
- Need storage batteries if not connected to grid

1 KW Photovoltaic Roof Panel

10.2 KW Solar Power Plant

36.3 KW Solar Power Plant

- 484 PV panels, 75 Watts each
- 240 storage batteries, 2 volts each
- Life of Batteries: 6 to 7 years

Cost Comparison of DG Technologies

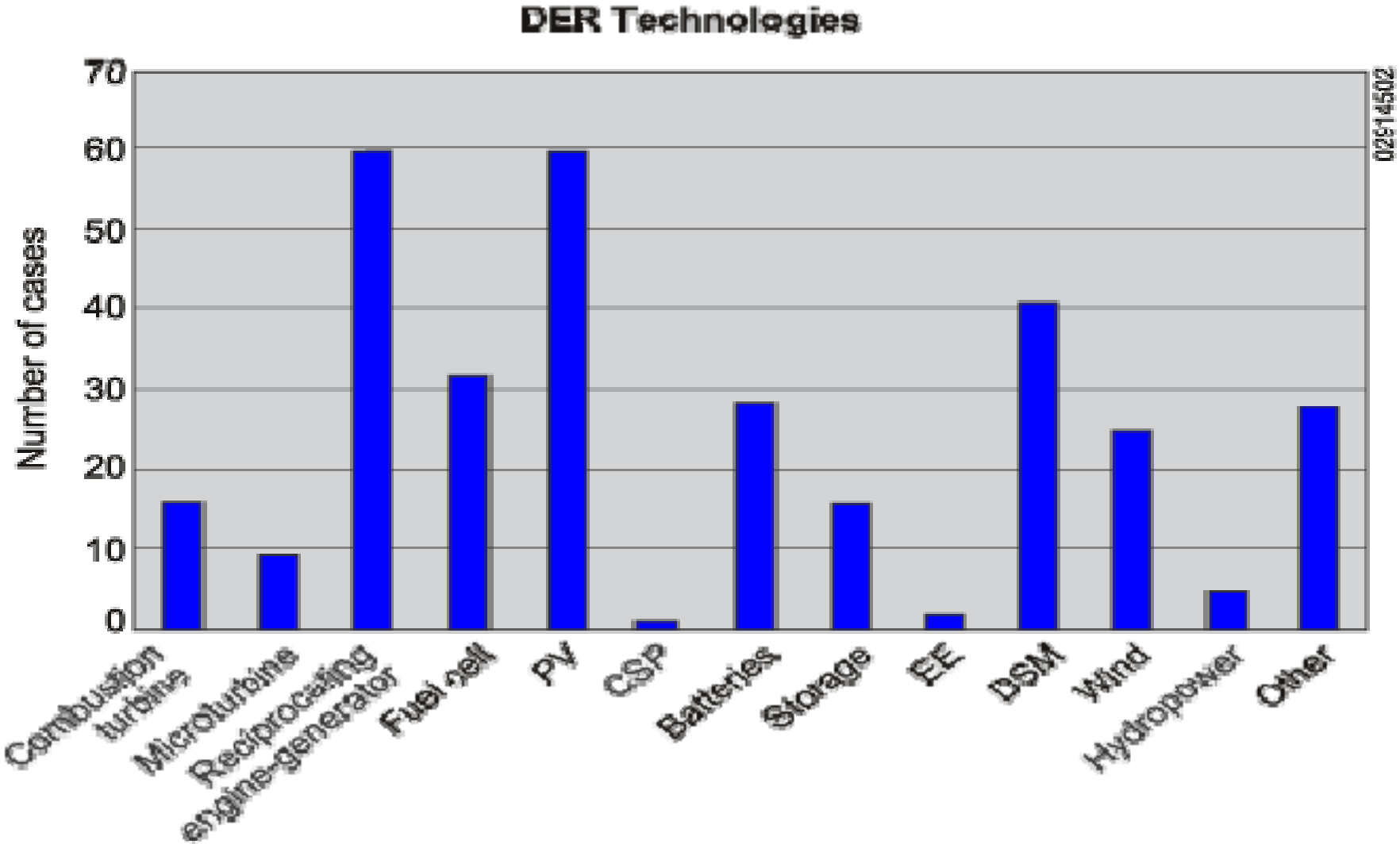
	IC Engines	Comb. Turbines	Micro-turbines	Fuel Cells	Wind Turbines	Solar Panels
Size Range per prices	50 KW – 5 MW	1 MW – 50 MW	25 KW - 75 KW	1 KW – 200 MW	10 KW – 1 MW	1 KW – 1 MW
Installed Cost ($/kWh)	$800 – $1500	$700 – $900	$500 – $1300	>$3000	$1000	$6000 - $8000
O & M Costs (¢/kWh)	0.7 – 1.5	0.2 – 0.8	0.2 – 1.0	0.3 – 1.5	1.0	0.1 – 0.4

Usage Comparison of DG Technologies

- A 1999 U.S. DOE report, *Distributed Utility Perspectives*, examined 275 Distributed Generation projects in the United States, managed by 121 different companies, to find out which DG technologies were being used. The report found that the most popular DG technologies are:
  - Reciprocating engine-generators (primarily diesel).
  - Solar electric power systems (photovoltaics, or PV).
  - Demand-side management (DSM) technologies aimed at reducing overall energy consumption.

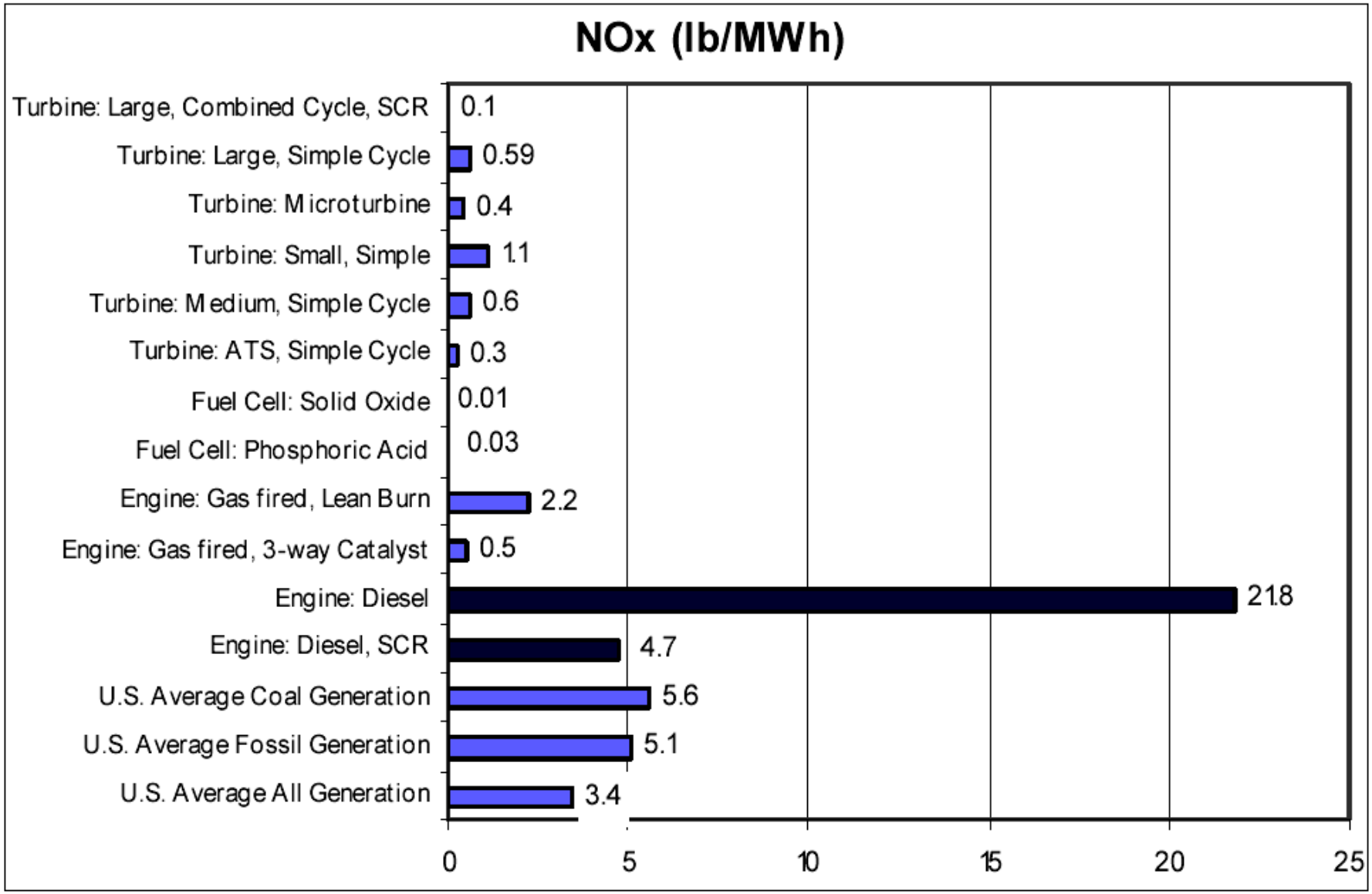
DOE Survey Results

(Source: Distributed Utility Associates)



- CSP - Concentrating Solar Power plants. They produce electric power by converting the sun's energy into high-temperature heat using various mirror configurations. The heat is then channeled through a conventional generator.
- EE - Energy Efficiency.
- DSM – Demand Side Management

Comparison of Typical Nitrogen Oxide (NOx) Emission Rates For Distributed Generation



Uses For DG Technologies

- Emergency or backup generation
  - Used by a facility to provide its own power in cases of grid power loss or failure
- Peaking units
  - Connected to the grid to supplement power from central power plants during peak demand
- Interruptible service program
  - a demand-side management program for facilities with backup generators not connected to the grid. During peak demand, electricity from the grid is cut off to participating facilities , and the backup generators are switched on to provide the facilities' own power, thereby reducing demand on the grid.

Delaware Interruptible Service Programs

- **Conectiv**
  - 10 customers – all commercial/industrial
  - Total capacity of 16.7 MW
  - All generators are diesel-powered
  - All customers are called on simultaneously
- **Delaware Electric Cooperative**
  - 217 customers (215 agricultural, 2 other businesses)
  - Total capacity of about 20 MW
  - 97.5 % of generators are diesel-powered
  - All customers are called on simultaneously

Diesel Generators – the positive factors

- Diesel engines are affordable, durable, reliable, low-maintenance, easy to operate
- Quick startup
- Fuel availability is high
- Fuel cost is low
- Diesel-powered IC engines are one of the most efficient forms of generation

Comparison of Electric Efficiencies of DG Technologies

	Gas-Fired Engine	Diesel Engine	Gas Combustion Turbine	Micro Turbine	Fuel Cells	Photo-voltaic	Wind Turbine
Electric Efficiency (LHV)	25-45%	30-50%	25-40%	20-30%	40-70%	15-30%	20-46%

Key: LHV= Lower Heating Value. The potential energy in a fuel if the water vapor from combustion of hydrogen is not condensed.

Diesel Generators - the negative factors

- Diesel generators without emission controls are the highest emitting form of distributed generation.
- The vast majority of diesel generators do not have emission controls.
- Most widely used technology for DG.
- According to the Renewable Energy Policy Project (REPP) there were 667,626 diesel generators in the U.S. in 1998, with a total generating capacity of 108.7 gigawatts (GW).
- The annual growth rate for diesel is 1.7 %, which equals 3.3 GW of diesel generating capacity added in the U.S. each year.

Diesel Generators in Delaware – more negatives

- Delaware is particularly vulnerable to diesel emissions because the State is in non-attainment of the national ambient air quality standard (NAAQS) for ground-level ozone.
- NOx emissions lead to the formation of ground-level ozone.
- Diesel generators have the highest NOx emission rate of any DG technology.
- During the ozone season when interruptible service programs are activated, Diesel generators emit NOx at a higher rate than any central power plant in Delaware.

To make matters worse…

- **Peak load days (days of DG use) most often occur in the hot summer months and frequently correspond with Ozone alert days – bad timing for diesel generators with their high NOx emissions.**
- **In the 2002 peak ozone season in Delaware there were 15 code red ozone action days.**
- **On 11 out of the 15 code red days (73%), interruptible service programs were activated to handle increased demand.**

Comparative Emissions Scenario

- Assume high demand on hot summer day, requiring additional 10 MW of electricity for 8 hours.
- If additional demand is met by Conectiv Hay Road turbine (LAER controls): 0.004 tons of additional NOx Emissions.
- If additional demand is met by uncontrolled diesel generators: 1.8 tons of additional NOx Emissions (450 times the emissions from the Hay Road turbine.
- 1.8 tons is almost one half of the **daily** emissions from Indian River Unit 4 -- Delaware's highest NOx emitting central power plant.

EPA NOx SIP Call

- Delaware must comply because of its non-attainment of the ozone national ambient air quality standard.
- Compliance deadline is 2007.
- Delaware is assigned NOx budgets for each category of emission sources, and a total statewide budget.
- To comply, Delaware can reduce emissions from any source categories it chooses.

NOx SIP Call

- To comply, Delaware has chosen to set the EGU budget at a 10 % reduction, and the non-EGU budget at a 12 % reduction.
- But the stationary area, on-road mobile and off-road mobile source emissions must not be allowed to grow.
- Therefore, Delaware must stem the growth in NOx emissions due to the growing use of uncontrolled fossil fuel generators for distributed generation.

Delaware's NOx SIP Call Budget

SOURCE CATEGORY	EMISSIONS W/O SIP CALL (tons/O_3 season)	2007 SIP CALL BUDGET (tons/O_3 season)	REDUCTION (tons/O_3 season)	REDUCTION (%)
EGUs	5,838	5,250	588	10
Non-EGUs	2,821	2,473	348	12
Stationary Area	1,129	1,129	0	0
On-Road Mobile	8,358	8,358	0	0
Off-Road Mobile	5,651	5,651	0	0
Total	23,797	**22,861**	936	4

NOx SIP Call

- EGUs and non-EGUs are limited to a 0.15 LB/MMBTU emission rate, with the option of purchasing NOx credits to comply.
- By comparison, the typical uncontrolled diesel generator emits NOx at a rate of 3.57 LB/MMBTU (24 times the EGU/non-EGU rate).
- Therefore, any significant shift from central power plants to diesel generators to meet peak demand by 2007 could cause Delaware to exceed its total NOx budget.

NOx Emission Controls for Diesel Engines

1. Add-on controls (for new and existing units):
   A. Exhaust controls
   B. Fuel Treatments
2. Dual-fuel conversion to natural gas plus diesel (existing units)
3. Combustion control technologies (new units).

1. Add-on Diesel NOx Controls

A. **Exhaust Controls:**

- **Selective Catalytic Reduction (SCR)** – uses a precious metal or Zeolite catalyst plus ammonia or urea to chemically reduce NOx to nitrogen gas (N_2). Low sulfur fuel must be used.
- **Catalytic Adsorption (SCONOx)** – uses a precious metal oxidation catalyst plus hydrogen regeneration to oxidize NO to NO2. Catalyst surface is treated with potassium carbonate coating for adsorption of NO2. Hydrogen gas is passed across surface of saturated catalyst to chemically reduce NO2 to N2 and water.
- **Selective Non-Catalytic Reduction (SNCR)** – injects ammonia or urea into regions of the exhaust with temperatures greater than 1400 – 1500 degrees F. The nitrogen oxides are chemically reduced to nitrogen gas and water vapor.
- **Lean NOx Catalyst** – injects diesel fuel into exhaust gas to add hydrocarbons, which chemically reduce NOx to nitrogen gas and water vapor.
- **Ozone Injection** – an on-site ozone generator injects ozone into a reactor duct to oxidize nitrogen oxides to highly water-soluble nitrous pentoxide (N2O5). Water or a caustic scrubber washes the N2O5 into a solution for removal.

1. Add-on Diesel NOx Controls (cont'd.)

B. **Fuel Treatments**

- **Fuel Additives** – usually proprietary formulations of chemicals or fuel-borne catalysts that claim to improve efficiency and lower combustion temperature. Catalysts can cause emissions of metals such as cerium, copper, platinum and manganese.
- **Fuel Emulsification** – incorporating water into fuel to lower combustion temperature. Is prone to separate into water & oil layer and has limited storage life. Can require special fuel filter.
- **Fuel Treatment Catalyst (Rentar)** - Canister added before fuel intake. Claims to improve combustion and efficiency.

NOx Control Efficiency of Add-On Diesel Controls

Emission Reduction Technology	Diesel-Fueled CI Engines
Selective Catalytic Reduction (SCR)	90 – 98%
Catalytic Adsorption (SCONOx)	80 – 90%
Selective Non-Catalytic Reduction (SNCR)	50 - 95%
Lean NOx Catalyst	90% or better
Ozone Injection	85 - 95%
Fuel Additives	< 10 %
Fuel Emulsification	18 – 29%
Fuel Treatment Catalyst	5 -19%

2. Dual-fuel conversion

- 100% natural gas cannot be burned in compression ignition engines due to high ignition temperature of gas. Some diesel must be present to produce “pilot ignition”.
- Natural-gas-to-diesel mix will vary with engine requirements. Range is 50 to 90 % natural gas, with 70% being typical.
- Converted engines can still burn 100% diesel on demand.
- NOx control efficiency ranges from 10% to 65%.

3. Combustion control technologies

- **Ignition or Spark Timing Retard** – moves ignition to later in the power stroke where there is less compression. Peak flame temperature is lowered.
- **Water Injection** – injects water into intake system, reducing air charge temperature during intake stroke.
- **Exhaust Gas Recirculation** – re-circulates exhaust gases containing roughly only 8-9% oxygen. Gases act as heat sink to lower peak combustion temperatures.
- **Aftercooling** – Lowers intake charge air temperature thereby lowering peak cylinder temperatures.

NOx Control Efficiency of Diesel Combustion Control Technologies

Combustion Control Technology	Diesel-Fueled CI Engines
Ignition or Spark Timing Retard	20 – 30%
Water Injection	25 – 30%
Exhaust Gas Recirculation (EGR)	48 – 80%
Aftercooling	Not Determined

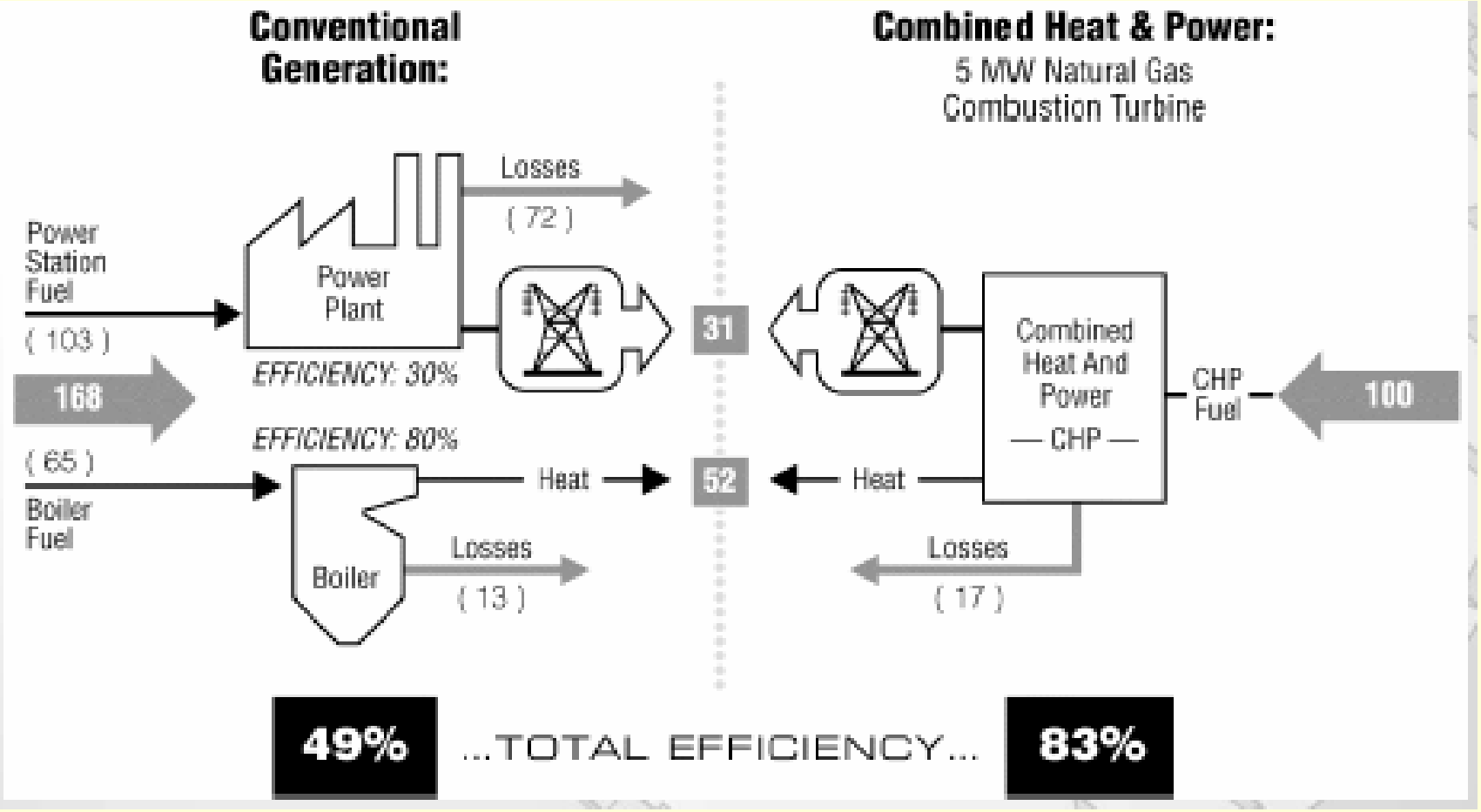
Combined Heat and Power (CHP)

- Combined Heat and Power is the generation of electricity and heat sequentially from the same heat input
- Normally wasted thermal energy is collected and used for industrial processes or space heating and/or cooling.
- Can be applied to virtually any fossil-fueled generator. Systems range from 25 KW on up.

CHP

- Use of CHP increases the efficiency of the engine.
- Provides electric and thermal service with higher efficiency and lower emissions than conventional separate systems.
- Can provide a way to reduce emission rate without the application of emission controls.
- Multiple outputs of engine (power and heat) must be accounted for.
- Therefore, output-based regulation is key to recognizing efficiency benefits of CHP. (Example: LB/MWh output instead of LB/MMBTU input.)

Efficiency Benefits of CHP



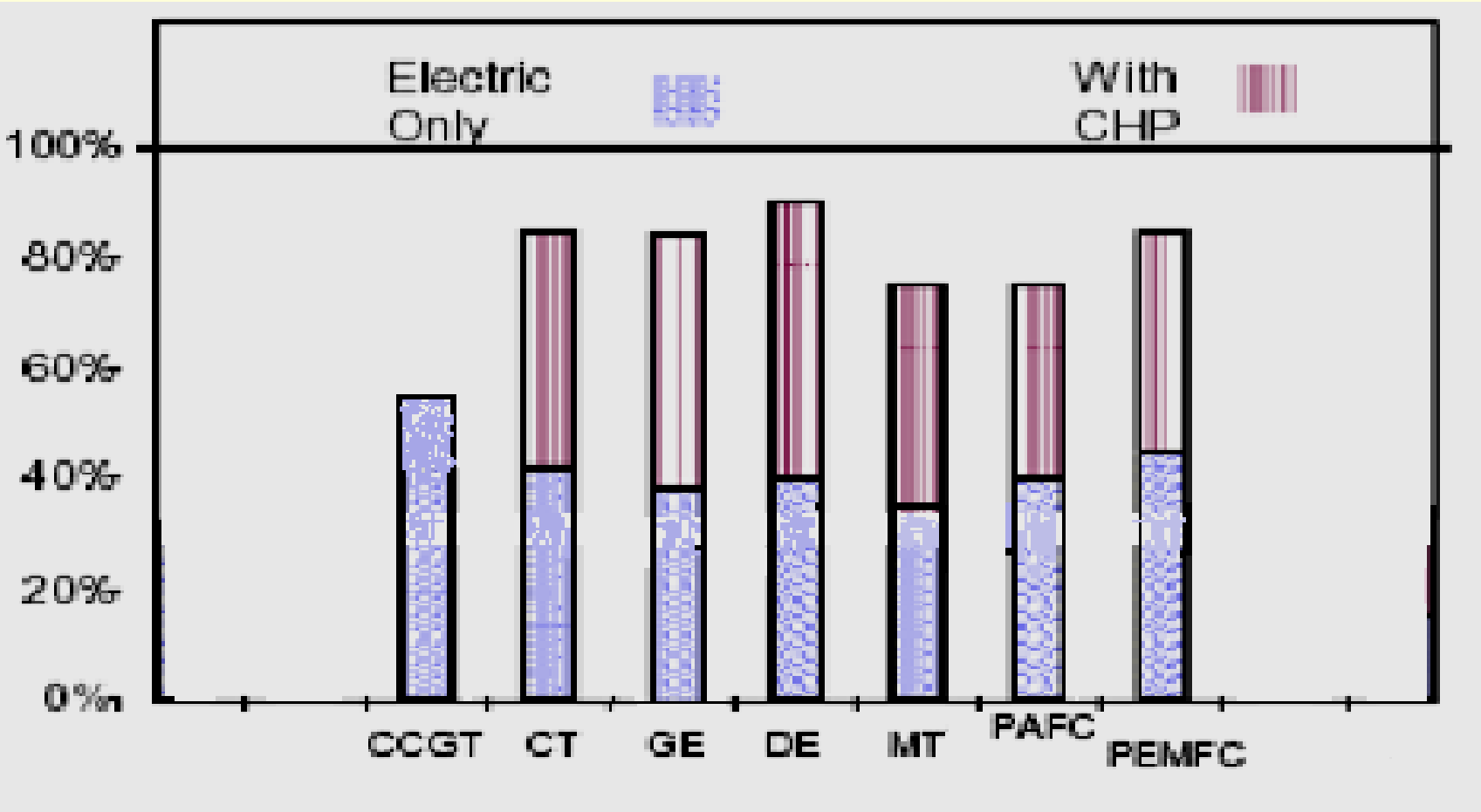
- The diagram compares the typical fuel input needed to produce 31 units of electricity and 50 units of heat from a conventional vs. CHP source.

Efficiencies of Technologies With/Without CHP

Technology	Electric Efficiency (%)	Total Efficiency (%)	NOx (Lb/MWh)	NOx (Lb/MWh$_{e+th}$)
CCGT	40-60%	N/A	0.3 - 3.0	N/A
Gas Turbine	25-40%	<85%	1.0 - 4.4	0.2 – 2.0
SI Engine	25-45%	<85%	2.2 – 28.0	1.0 - 12.0
CI Engine	30-50%	<90%	3.0 – 33.0	2.0 – 15.0
Microturbine	20-30%	<75%	0.4 – 2.0	0.2 – 1.0
Fuel Cells	40-70%	<75%	<0.02	<0.01

- Source: The Clean Air-Innovative Technology Link, Northeast-Midwest Institute

Efficiencies With/Without CHP



- Key: CCGT (combined cycle gas turbine, annual avg. w/T&D), CT (combustion turbine), GE (gas-fired spark ignition engine), DE (diesel compression ignition engine), MT (microturbine), PAFC (phosphoric acid fuel cell, PEMFC (proton exchange membrane fuel cell).

Calculating Emissions From CHP: Two Approaches

1. Add thermal output to electric output to reduce effective emission rate. (CA & TX DG Regs.)
2. Calculate credit for avoided thermal generator (boiler). (RAP Model Rule)

- First option is simpler. Second option more directly reflects actual emission benefits.

Comparison of Two Approaches

1. Thermal Output Approach:

   CHP Emissions = Actual Emissions/(MWh_e + MWh_{th}*)*

2. Displaced Emissions Approach:

   CHP Emissions =

   (Actual Emissions – Avoided emissions)/MWh_e

   Avoided emissions are the emissions that would have been created by a boiler providing the same thermal output.

Current DNREC Permitting Requirements for Generators

- **A unit with a rated heat input capacity of 10 mmBtu/hr or greater requires a Regulation 2 permit.**
- **Any new or modified unit qualifying as a major new source or major modification requires a New Source Review Permit (Regulation 25), or a synthetic minor permit (Regulation 2).**
  - **Definition of major source of NOx is currently 25 TPY potential to emit in Kent & New Counties, 100 TPY in Sussex County.**
  - **In general, a unit equal to 184 HP, 137 KW or 1.3 – 1.5 mmBtu/hr heat input (depending on efficiencies) will have 25 TPY of potential NOx emissions.**
  - **Potential to emit is based on 8760 operating hours per year, unless enforceable permit restrictions are secured. An exception to this is units that operate only as emergency units, which may base potential to emit calculations on 500 operating hours/yr. Emergency units cannot participate in interruptible service programs and cannot be tested on ozone action days.**

Current DNREC Registration Requirements for Generators

- Units must submit a registration form if they:
  - are not required to obtain a Regulation 2 permit.
  - have aggregated emissions of all air contaminants, before the application of controls, which are greater than 0.2 lb/day but less than 10 lb/day.

Current DNREC Recordkeeping Requirements For Generators

- Units with permits are required to keep logs of operating hours and fuel usage.
- In addition, major NOx sources (Regulation 12) are required to submit an initial compliance certification, keep all compliance-related records for 5 years, and report any occurrences of excess emissions.

Some Existing State DG Regs. And Model Rules

- OTC Model Rule
- RAP Model Rule
- California Regulation
- Texas Regulation

Summary of Recommended/Adopted Distributed Generation Emissions Standards

	Emission Limits (lb/MWh)					
Regulation	**NOx (Ozone Attainment Areas)**	**NOx (Ozone Non-Attainment Areas)**	**CO**	**VOCs**	**PM**	**CO_2**
OTC Model Rule [a] - new and in-use engines (emissions factors converted from g/bhp-hr)						
Natural Gas (except emergency)	4.4	4.4				
Diesel (except emergency)	6.8	6.8				
RAP Model Rule - new engines						
After January 1, 2004	4	0.6	10		0.7	1900
After January 1, 2008	1.5	0.3	2		0.07	1900
After January 1, 2012	0.15	0.15	1		0.03	1650
California Air Resources Board						
Distributed Generation Certification Rule for New Non-Emergency Engines						
After January 1, 2003	0.5	0.5	6	1	fuel req. [b]	
After January 1, 2007	0.07	0.07	0.1	0.02	fuel req. [b]	
Texas - new engines						
Before January 1, 2005						
less than 300 hrs/yr	21	1.65				
more than 300 hrs/yr	3.11	0.47				
After January 1, 2005						
less than 300 hrs/yr	21	0.47				
more than 300 hrs/yr	3.11	0.14				

[a] The OTC Model Rule offers three compliance options: 1) meet the NOx emission limit specified above, 2) meet a percentage reduction of NOx emissions specific to the type of engine, and 3) purchase of NOx allowances.

[b] PM emission limit corresponding to natural gas with fuel sulfur content of no more than 1 grain/100 standard cubic foot.