Unexpectedly fundamental advances continue, *e.g.*:

- Biomimetic rotor from Pax Scientific, San Rafael, CA (www.paxscientific.com)
- Fibonacci spiral shape matches the natural pattern of laminar vortex flow found throughout nature
- If blood flowed through our bodies as inefficiently as water flows through our pipes, we'd need hearts bigger than our bodies—not our small ~1.5-watt hearts
- In fans, pumps, turbines, turboexpanders, etc., this peculiar rotor shape can usually raise efficiency by ~20–30 percentage points and reduce noise
- Computer muffin fans get 30% more flow/W or make 10 dBa less noise
- Extremely wide & diverse applications
- Commercialization is starting

Images courtesy of Pax Scientific

The right steps in the right order: space cooling

0. Cool the people, not the building
1. Expand comfort envelope
2. Minimize unwanted heat gains
3. Passive cooling
   - Ventilative, radiative, ground-/H_2O-coupling, icepond
4. Active nonrefrigerative cooling
   - Evap, desiccant (CDQ), absorp., hybrids: COP >100
   - Direct/indirect evap + VFD recip in CA: COP 25
5. ~~Superefficient refrigerative cooling: COP 6.8 (0.52 kW/t) (Singapore water-cld centrif. *system* @ design h)~~
6. Coolth storage and controls
7. Cumulative energy saving: ~90–100%, better comfort, lower capital cost, better uptime

A worthy goal: eliminate refrigerative air conditioning, including big commercial (responsible for ~1/2 of China's growth in peak el. demand)

Benchmarking a big new office

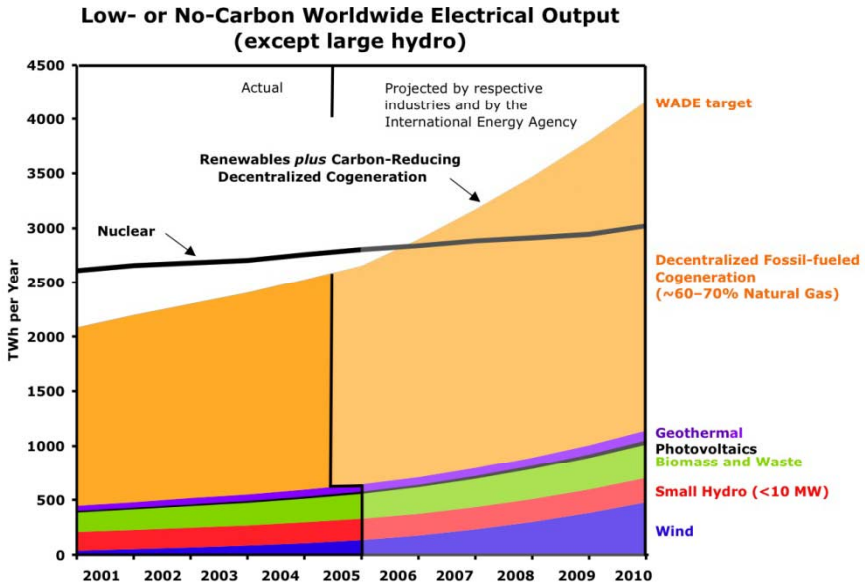
(~10,000+ m², semitropical climate; Japanese comparables)

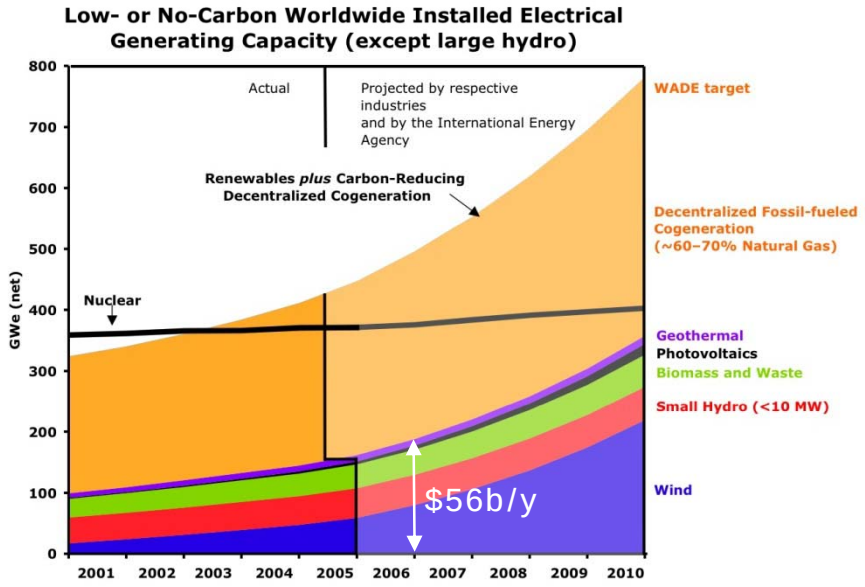
	standard US	better	best practice
site MJ/m²-y	1,100/1,737	450–680/566	100–230/293
el. kWh/m²-y	270/203	160/195	20–40/81
lighting W/m² as-used	16–24/12	10	1–3
plug W/m² as-used	50–90/12	10–20	2
glazing W/m²K COG	2.9	1.4	0.3–0.5
glazing T_{vis}/SC	1.0	1.2	>2.0
perimeter heating	extensive	medium	none
roof α, ε	0.8, 0.2	0.4, 0.4	0.08, 0.97
m²/kW_{th} cooling	7–9	13–16	26–32+
cooling syst. COP	1.85	2.3	6.8–25+
relative cap. cost	1.0	1.03	0.95–0.97
relative space eff.	1.0	1.01	1.05–1.06

Japan standard: median of 40 buildings, Energy Conservation Center of Japan; better: average of six SHASEJ Junen Award-winning buildings; best: the most efficient of those six buildings (Nissei Yokkaichi Building); data courtesy of Urabe-san, CRIEPI, via Asano-sensei, Dept. of Mechanical Engineering, The University of Tokyo

Electric shock: low-/no-carbon decentralized sources are eclipsing central stations

RMI analysis: www.rmi.org/sitepages/pid171.php#E05-04





- Two-thirds combined-heat-and-power (cogeneration)*, ~60–70% gas-fired, ≥50% CO_2 reduction

*Gas turbines ≤120 MWe, engines ≤30 MWe, steam turbines only in China

- One-third renewable (including hydropower only up to 10 MW_e)
- In 2005, these low- or no-carbon generators added 4× the output and 11× (excl peaking & standby units, 8×) the capacity nuclear power did
- *1/6 of el, 1/3 of new el, & rising*
- 1/6 to >1/2 of all electricity in 13 industrial nations
- Negawatts comparable or bigger, so *central plants' mkt share <50%*
- Micropower is winning due to lower costs & financial risks, so it's financed mainly by private capital (only central planners buy nuclear)

All options face implementation risks; what does market behavior reveal?

- California's 1982–85 fair bidding with roughly equal subsidies elicited, *vs.* 37-GW 1984 load:
  - 23 GW of contracted electric savings acquisitions over the next decade (62% of 1984 peak load)
  - 13 GW of contracted new generating capacity (35% of 1984 load), most of it renewable
  - 8 GW (22%) of additional new generating capacity on firm offer
  - 9 GW of new generating offers arriving per year (25%)
  - Result: glut (143%) forced bidding suspension in April 1985
  - Lesson: real, full competition is more likely to give you too many attractive options than too few!
- Ultimate size of alternatives also dwarfs nuclear's
  - El. end-use efficiency: ~2–3× (EPRI) or 4× nuclear's 20% US share at below its *short*-run marginal delivered cost
  - CHP: industrial alone is comparable to nuclear; + buildings CHP
  - On-/nearshore wind: >2× US & China el., ~6× UK, ~35× global*
  - Other renewables: collectively even larger, PVs almost unlimited
  - Land-use and variability *not* significant issues

*www.stanford.edu/group/efmh/winds/global_winds.html, on- and nearshore sites with annual mean windspeeds ≥6.9 m/s at 80m hub, ~72 TW