Solar Energy

Present and future

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Lecture 3.4 – 2018 Edition

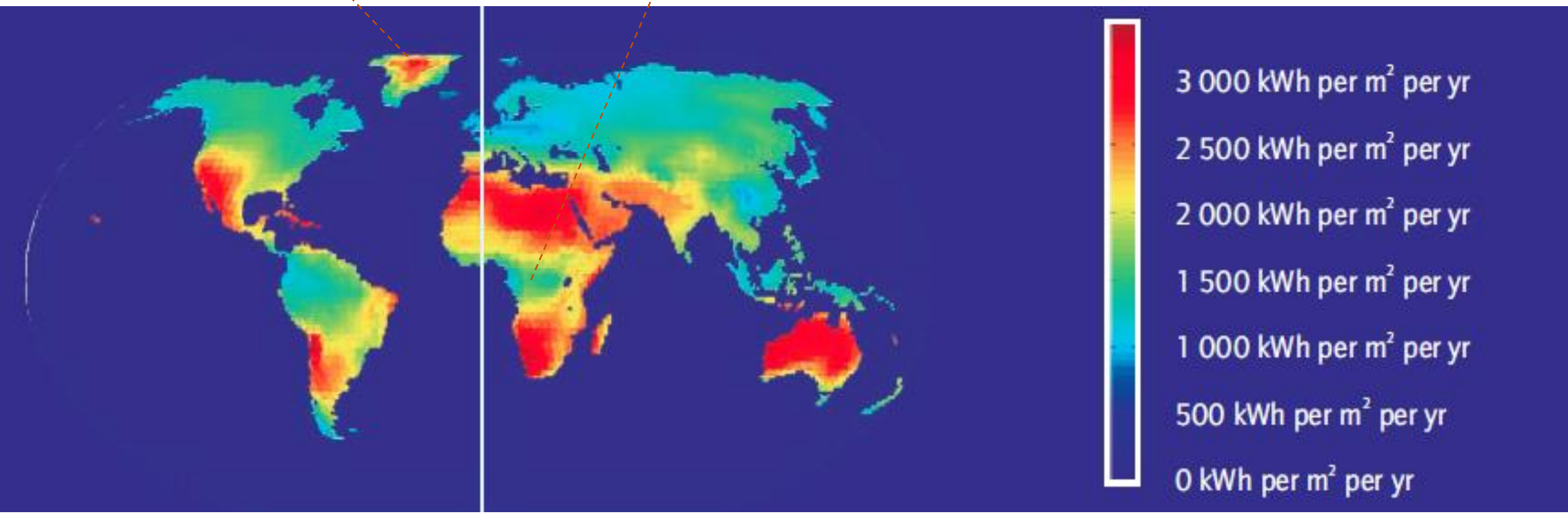
1. Solar Photovoltaic

Not solar thermal, not biomass (solar), not hydroelectric (solar)

Solar Map

Come visit Sunny Greenland!

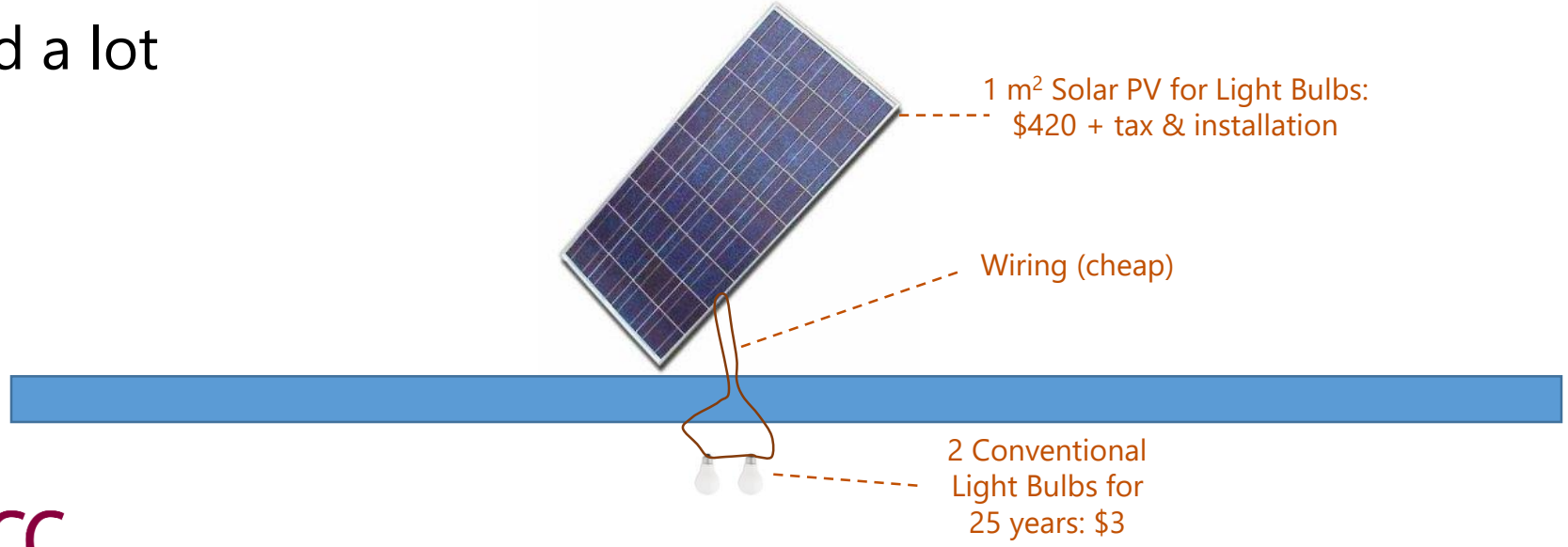
Tropics surprisingly not as good as you would think (rainy and cloudy).



Source: IEA, Concentrating Solar Power Technology Roadmap. 20107.

Solar Photovoltaics

- Convert sunlight directly to electricity
- DC Current
  - Need DC→AC conversion for grid transport
  - (~4% energy loss)
  - Although DC transmission lines are increasing.
- At optimal sunlight of 1kW/m^2, can recover 13% (130 W)
- So you need a lot of space



Source: Labouret, A. Solar Photovoltaic Energy. Ch 1 (2010).

How It Works

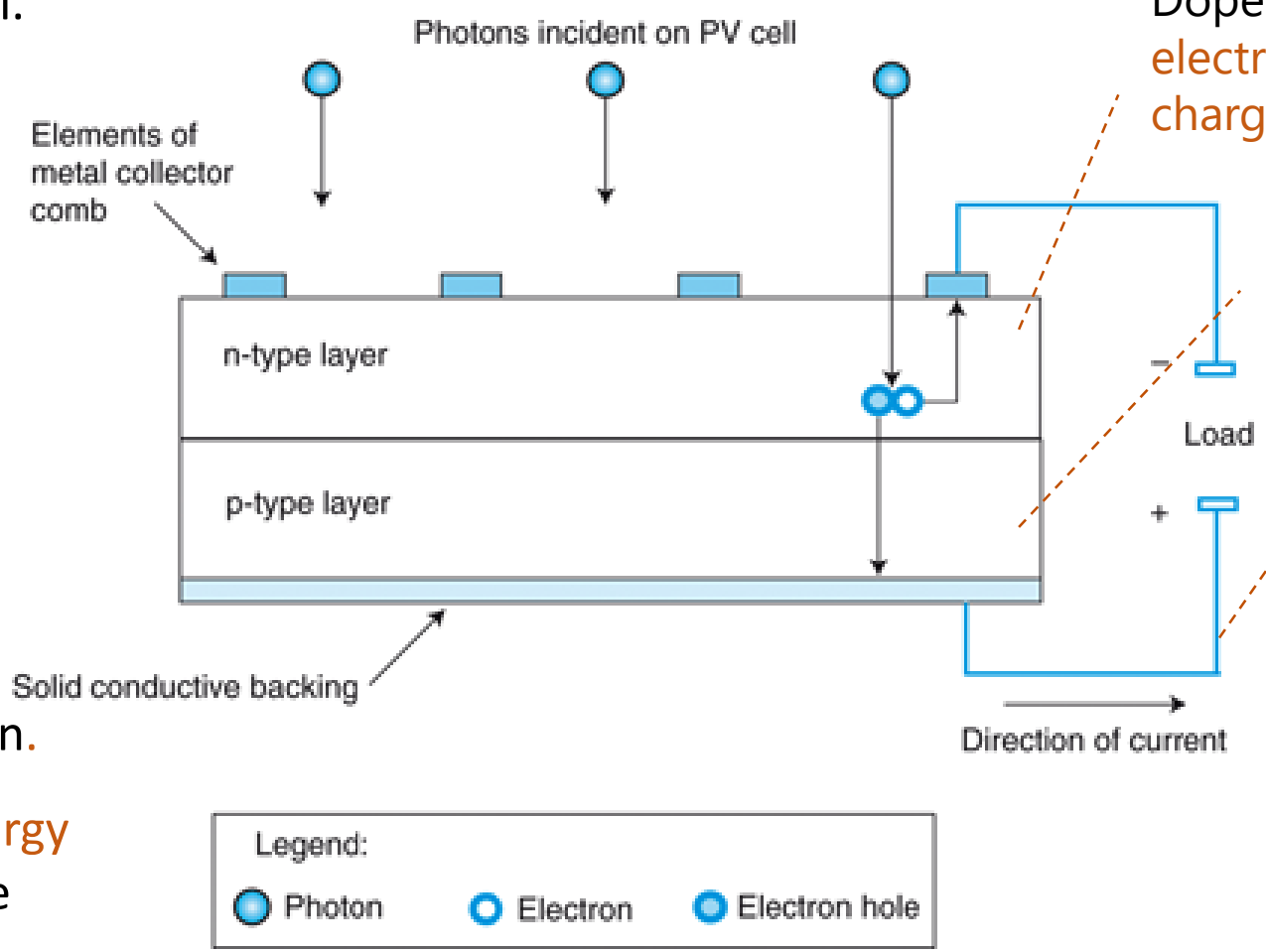
1. Photon heads toward cell.

2. A percentage will collide with atoms in the matrix. (Some will pass through).

3. If the photons have less energy than the bandgap energy, they bounce away

4. If they have more they dislodge an electron, now moving with high energy received via photon collision.

5. A percentage of high energy electrons will make it to the combs. The rest readsorb.



Doped to have excess electrons (net negative charge)

Doped to have electron receptors (net positive charge)

New electrons (of lower potential) arrive from the rest of the circuit. They travel "against" the current.

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Source:: B1 (Energy Systems Engineering 2nd Ed).

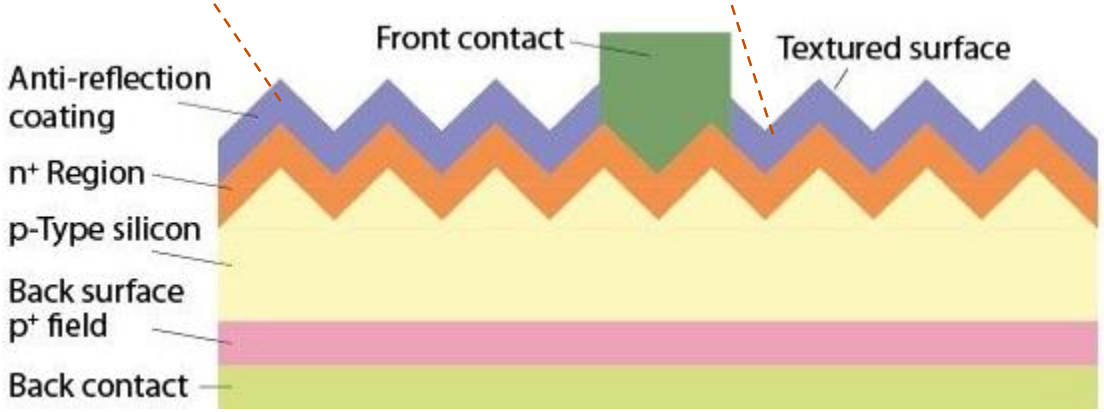
Panel Construction

You want an anti-reflective coating to avoid as many reflecting photons as possible

Black colour absorbs more photons than white

Combs / Contacts are the metal lines evident throughout

Ridges/texture causes bounced photons to bounce at an angle into the structure (increases chance of collision)

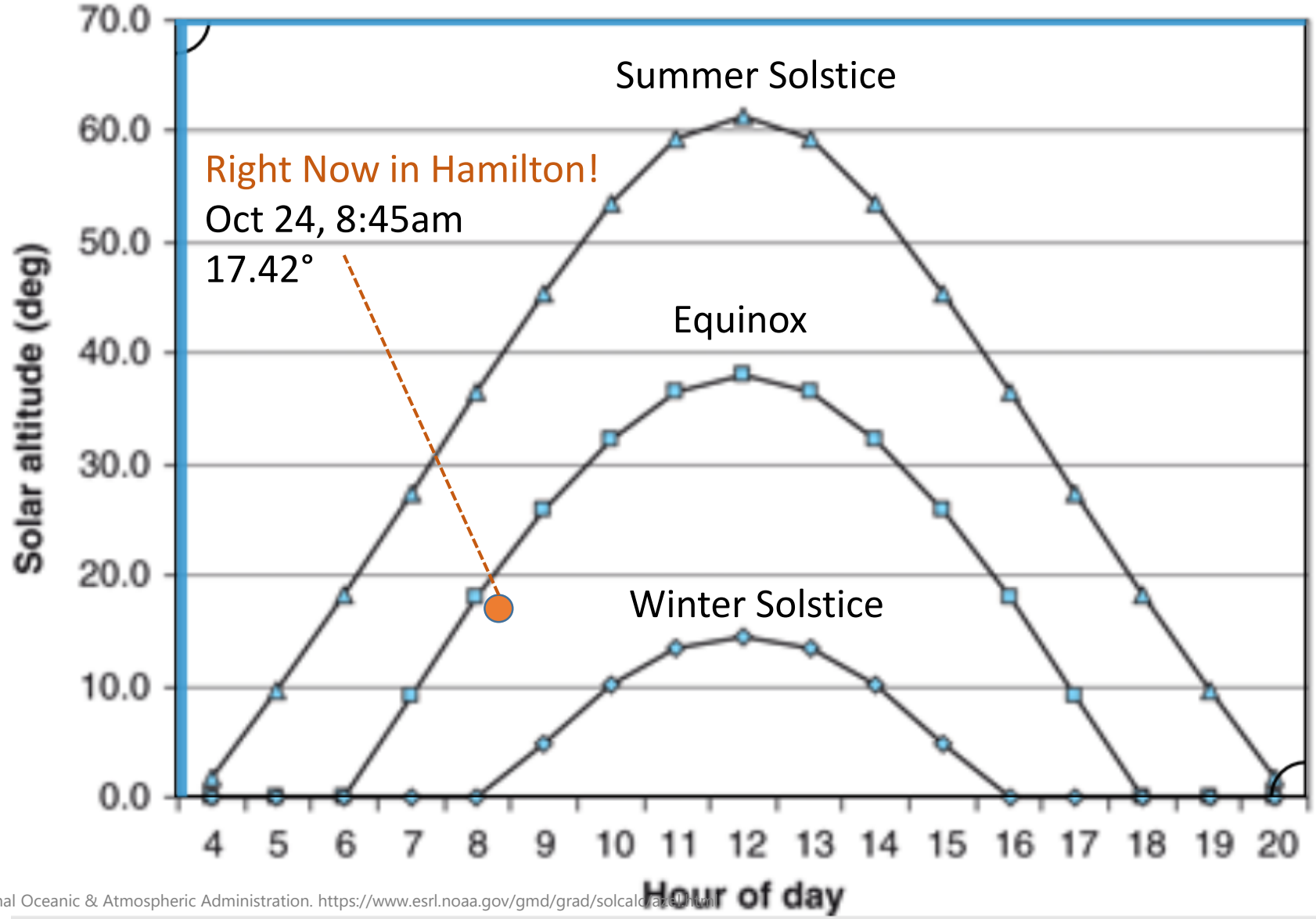


Monocrystalline silicon solar cell

Source:: Saga T. NPG Asia Materials volume 2, pages 96–102 (2010)

Large seasonal and hourly variations

- We know exactly where the sun will be at any time at any place on Earth
- Intensity is a function of angle, clouds, and other factors.
- This is for 52°N, Red Deer. AB. (Half way between Calgary and Edmonton)



Source: B1§9.3. Also National Oceanic & Atmospheric Administration. https://www.esrl.noaa.gov/gmd/grad/solcalc/calcdetail.html

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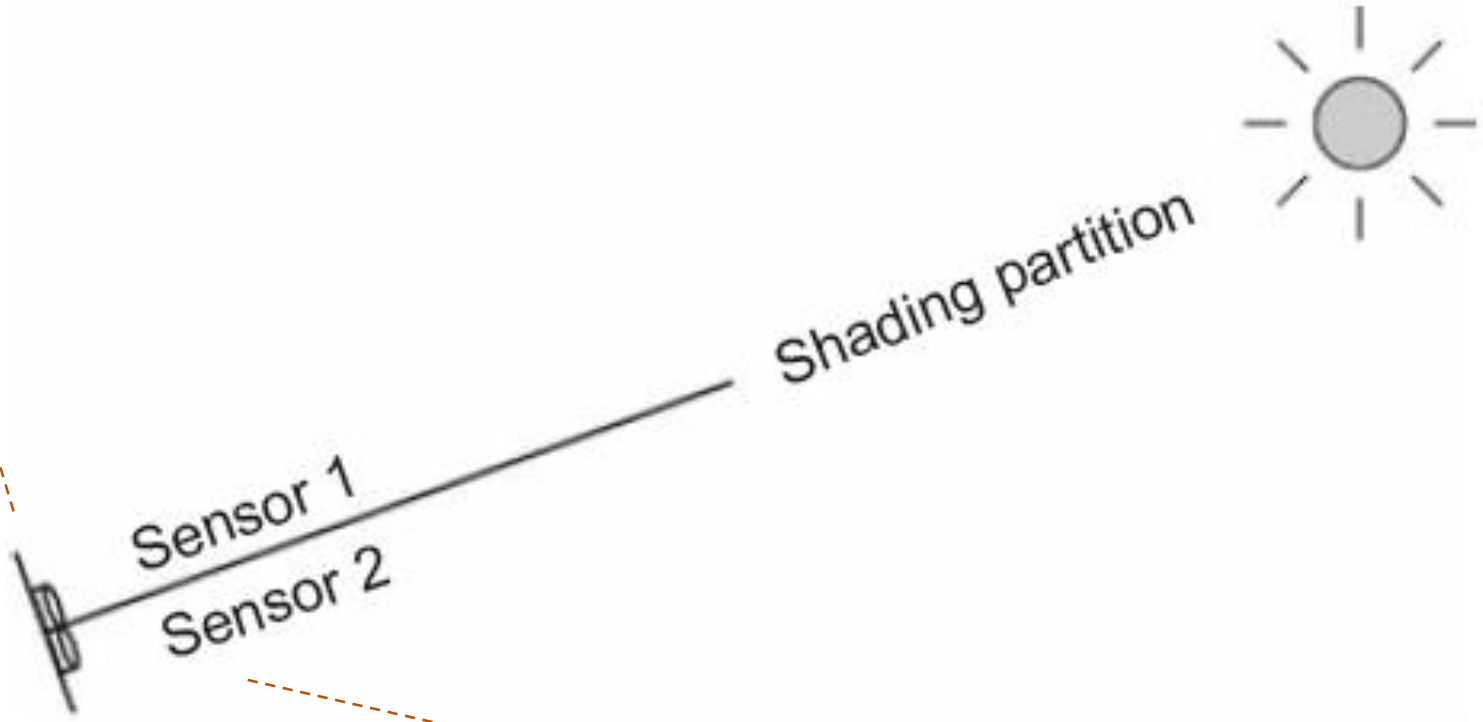
Solar Tracking Control

The panels are turned on a pre-programmed schedule (feed-forward)

When windy, the feedback corrector is intentionally disabled for safety.

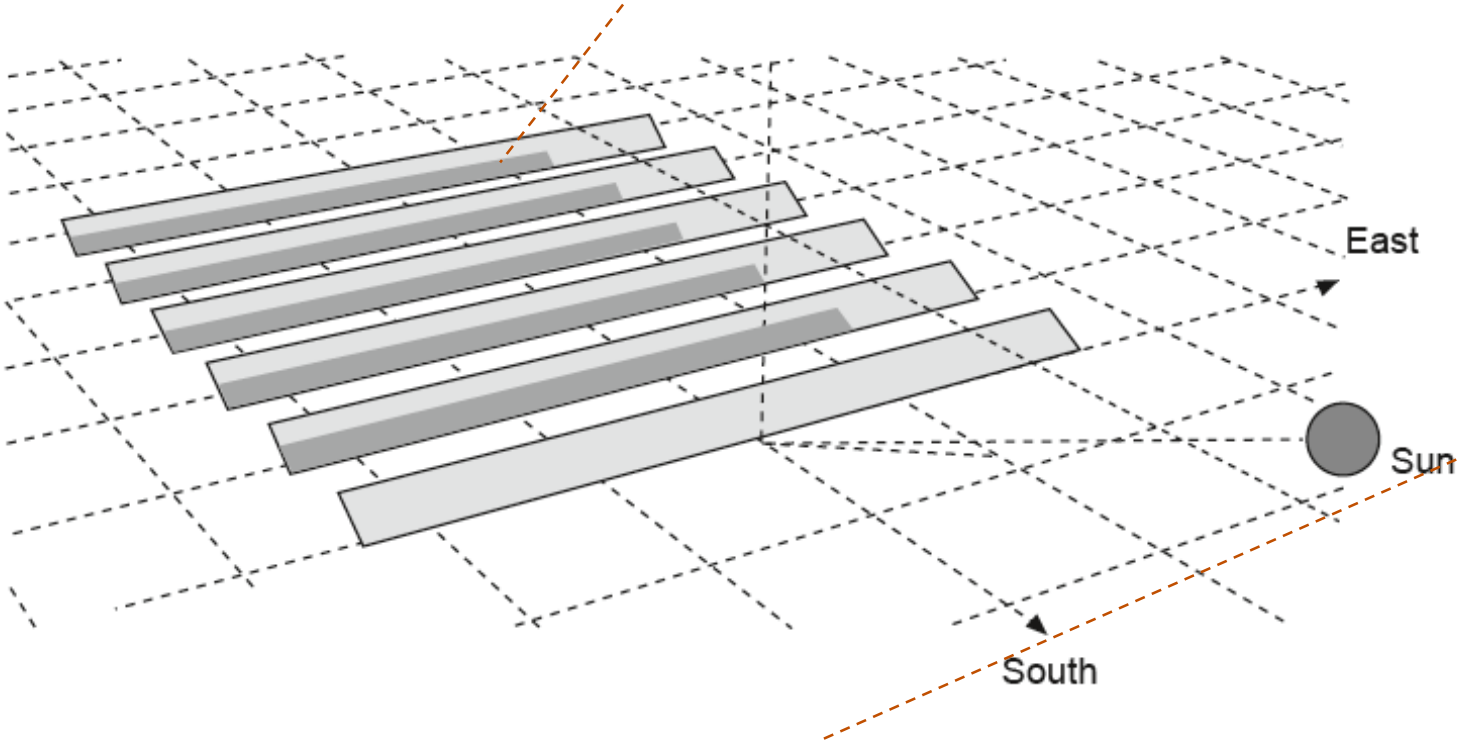


If one sensor collects more than another, it corrects in that direction (feedback)

Source: Labouret, A. Solar Photovoltaic Energy. Ch 4 (2010).

Shading

For large sets, have to correct for shading. Depends on geometry and season. This one is for low-angle (winter)



This is what we use in Sarnia, Ontario!

(b)

You can change the angle throughout the season with this kind of structure. You can't do that with roof mounted ones. Usually assumes roof angle.

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Source: Labouret, A. Solar Photovoltaic Energy. Ch 4 (2010). B1 (Energy Systems Engineering 2nd Ed). Fig 10-6, 10-8

2. Solar Thermal

Concentrating Solar Power

- Instead of large photovoltaic panels, sunlight is concentrated into small areas via parabolic reflectors.
  - "The intensity of 30,000 suns"
  - "Heliostat" trackers which slowly turn the reflectors throughout the day to maximize reflectiveness.
  - Used to heat a fluid, rather than directly produce electricity
  - A.k.a "Solar Thermal"
  - Expanding commercialization
  - 1 GW current capacity
  - Best for very sunny parts of the globe
    - Sorry Canada

Parabolic troughs most mature form

Fluid in hotpipe

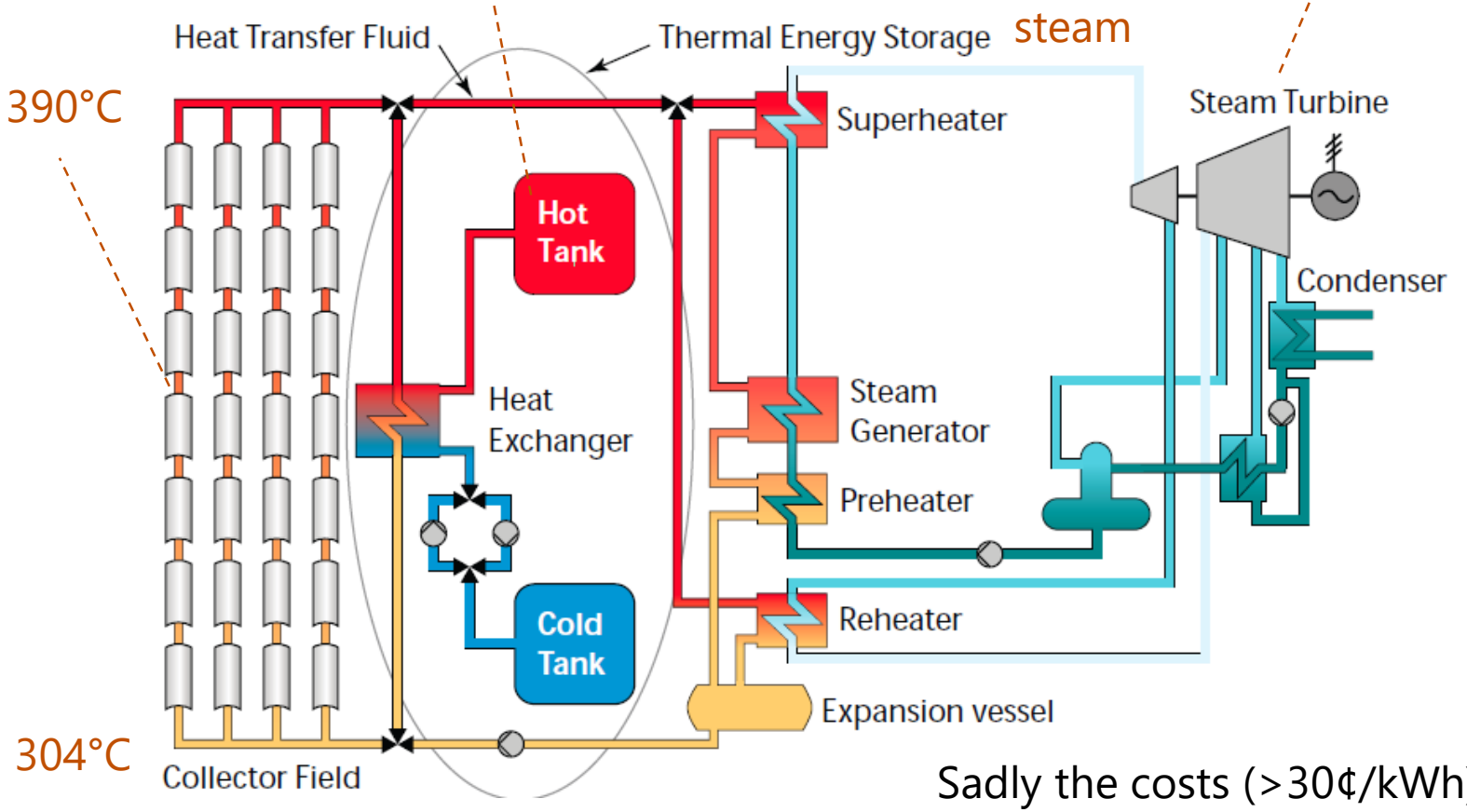
Source: US National Renewable Energy Laboratory. Concentrating Solar Power. (2010).
Young T, The UK Gardian, Egypt plans 100MW solar power plant. http://www.guardian.co.uk/environment/2010/jul/12/egypt-solar-power July 2010
See also Usaola J. IET Renew. Power Gener. 6:59-66 (2012)

CSP For "Thermal Solar"

Engine of Watt! unrivall'd is thy sway.
Compared with thine, what is the tyrant's power?
--from "The Steam Engine" by Ebenezer Elliott

Thermal storage (molten salts) enables control of when electricity is generated.
Don't need it, but that's the primary interest

50-100 bar steam



A variety of working fluids possible

Sadly the costs (>30¢/kWh) are about double photovoltaic solar, highest of all forms studied in this course.

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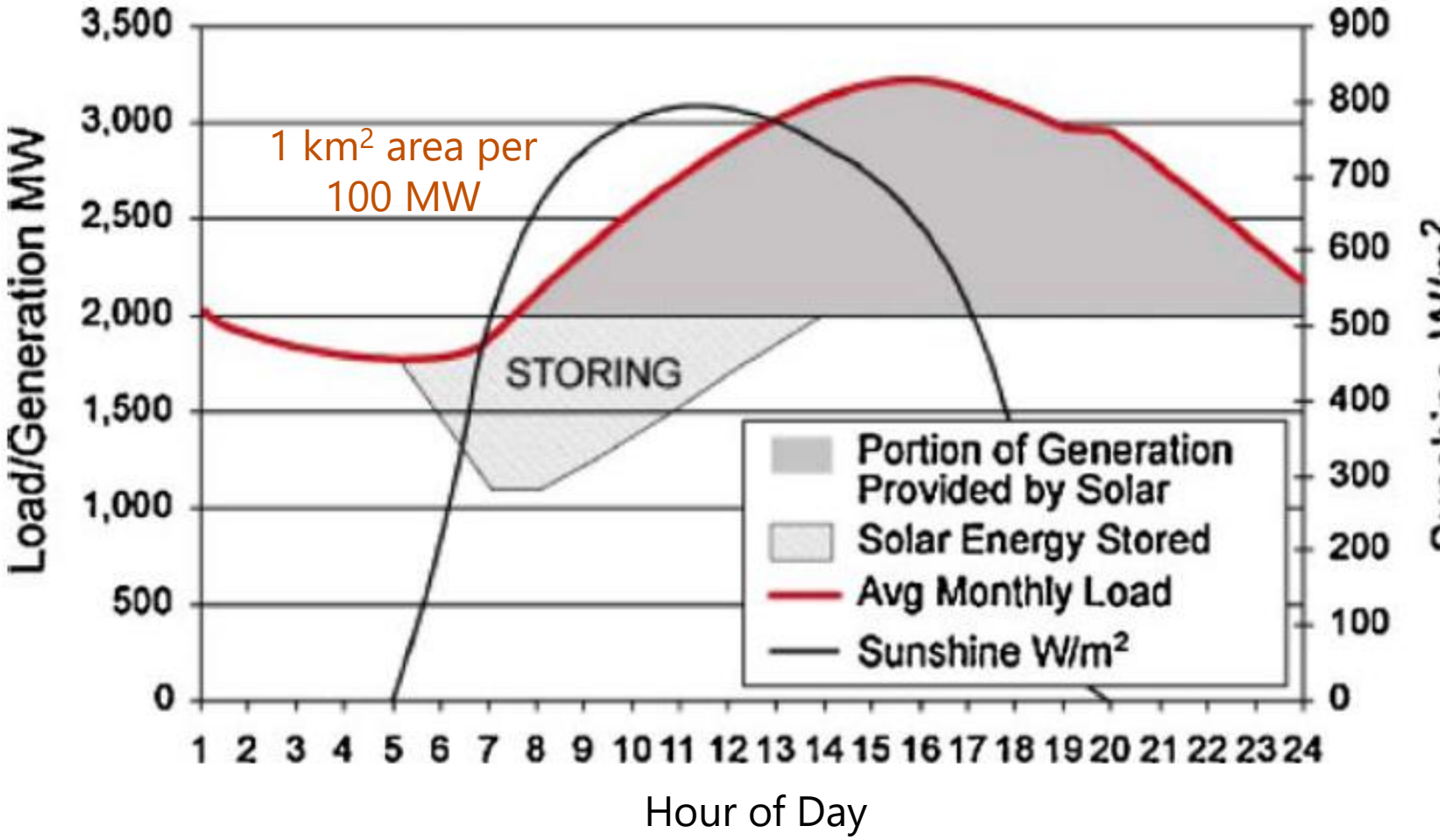
Source: US National Renewable Energy Laboratory. Concentrating Solar Power. (2010).
Usaola J. IET Renew. Power Gener. 6:59-66 (2012)

CSP Energy Storage

- It's the energy storage capabilities which make CSP attractive. Can't do it with PV Solar!
- Typically need enough for about four hours of storage.



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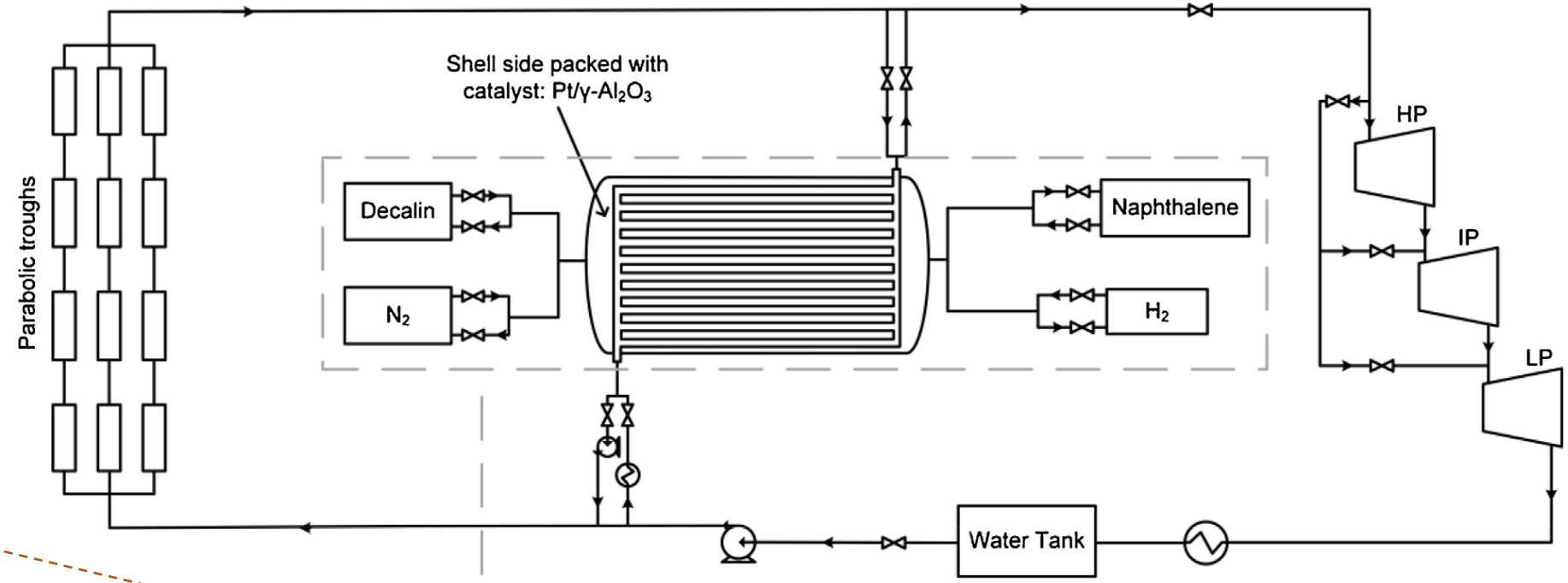
Source: M. Medrano et al. / Renewable and Sustainable Energy Reviews 14 (2010) 56–72
IEA, Concentrating Solar Power Technology Roadmap. 20107.

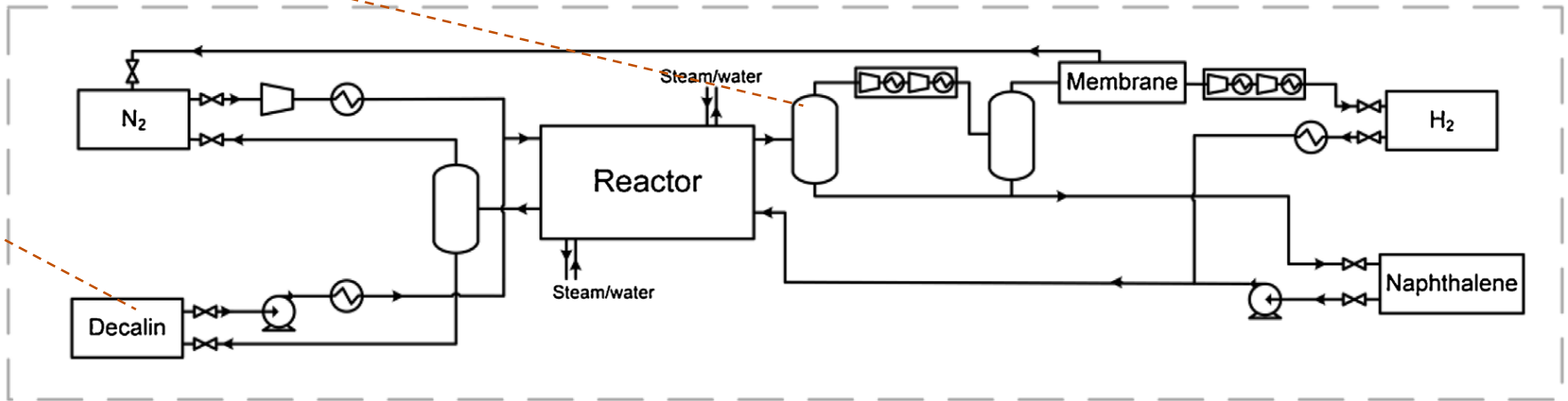
Chemical Storage for CSP

Decalin + Heat ⇋ Naphthalene + H_2

Requires little energy to separate NP from H_2 with (liq/gas)

Store at safe temperatures (~85°C) (advantage over molten salt)





Source: Lai H, Adams TA II. *Chemical Engineering Research and Design* 131:584–599 (2018)

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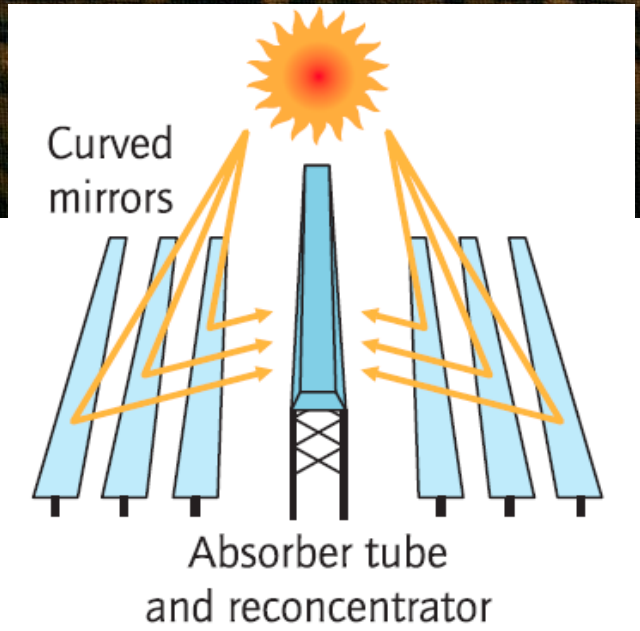
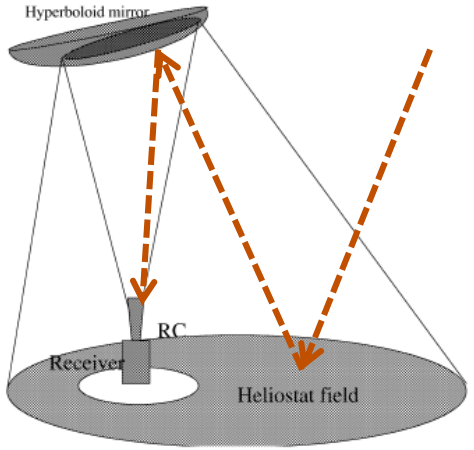
Other CSP Varieties

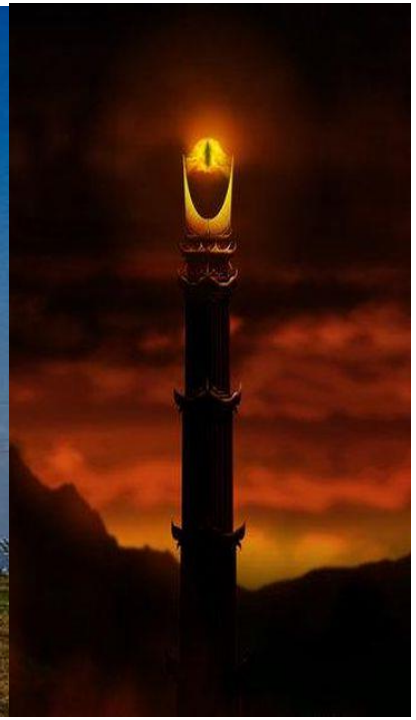
Linear Fresnel Reflectors
Less efficient but cheaper.



Solar Towers
Less efficient but cheaper.



This 11MW unit in Spain does not use the second reflector at the top.



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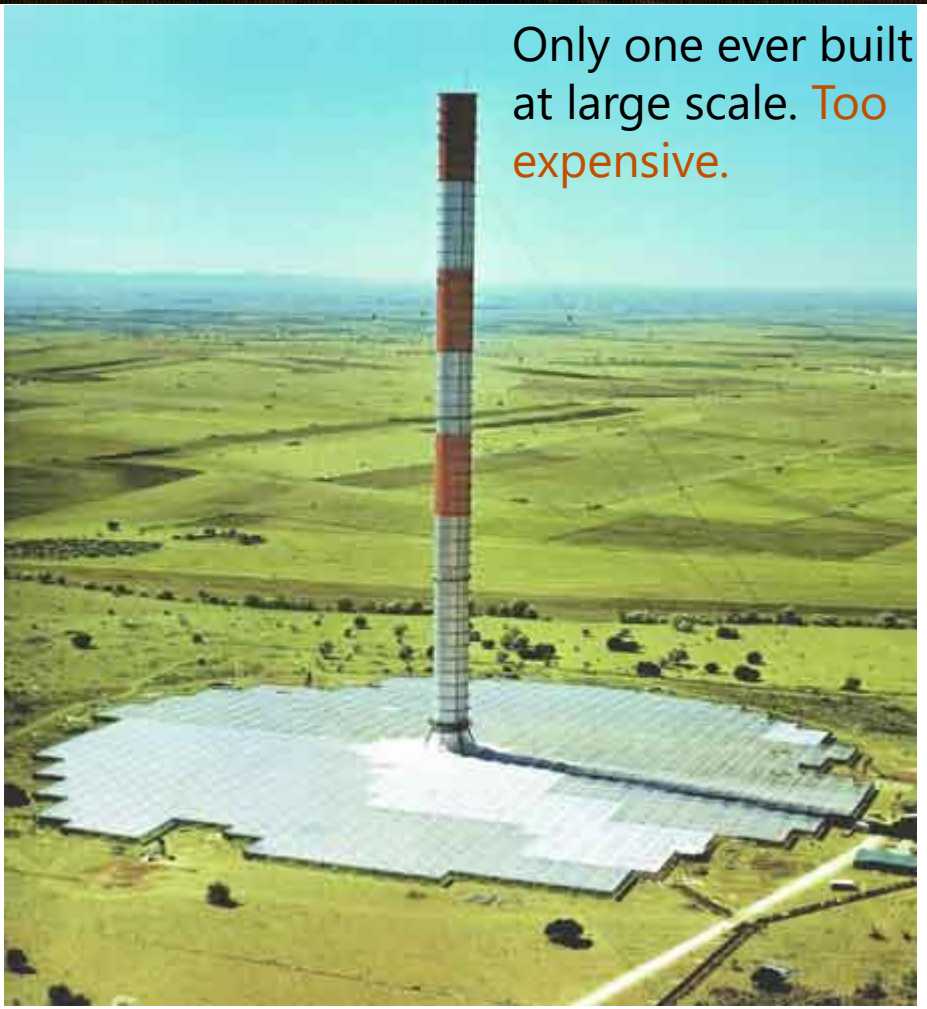
Source: Usaola J. IET Renew. Power Gener. 6:59-66 (2012) Photos from from wikipedia (sorry). See also IEA, Concentrating Solar Power Technology Roadmap. 2010
Segal A, Epstein M. The optics of the solar tower reflector. Solar Energy, 69S:229-241 (2000).
Shukman D. Power station harnesses Sun's rays. BBC News. May 2007.

Solar Chimneys aka Solar Updraft Towers



Only one ever built at large scale. Too expensive.

Operates under same principles as natural draft cooling towers.

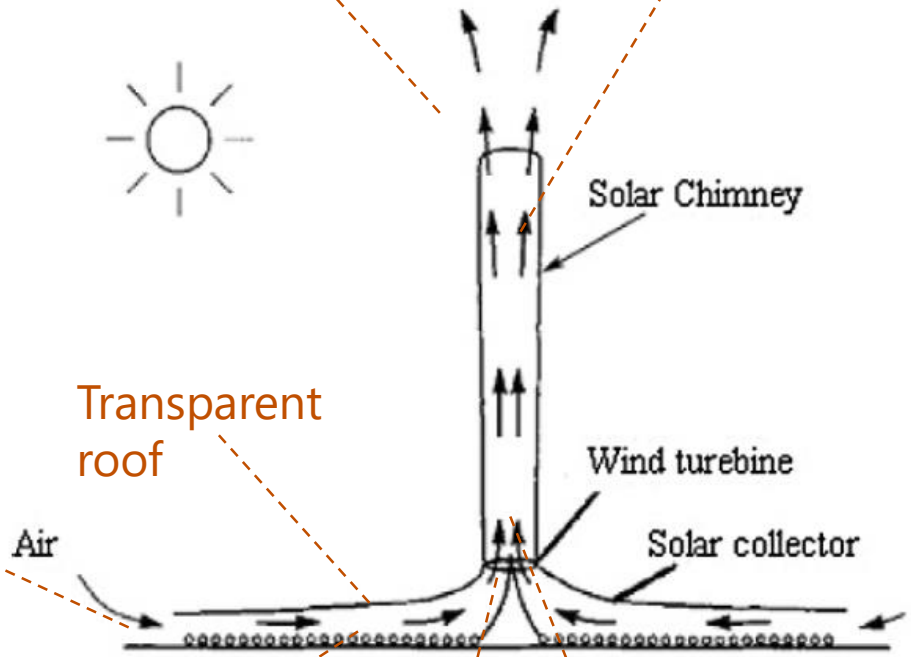
Hot air is less dense

$$RT = \frac{P}{\rho}$$

Outside density is bigger, so more air comes in due to buoyancy forces (gravity), which pushes it along

Air has lower pressure the higher you go

The taller the chimney, the faster the flow $Q \sim h^{0.5}$



Transparent roof

Air gets hot from greenhouse effect (~40°C)

Kinetic energy (pressure) converted to electric. Pressure drops.

Pressure output cannot be below top of chimney

Source: Cervone et al. Design of solar chimney power plant for Meditteranean countries. International Conference on Clean Electrical Power, p 480-4, 2011
Solar Energy, ed Radu Rugescu. Chapter 10 (2010).

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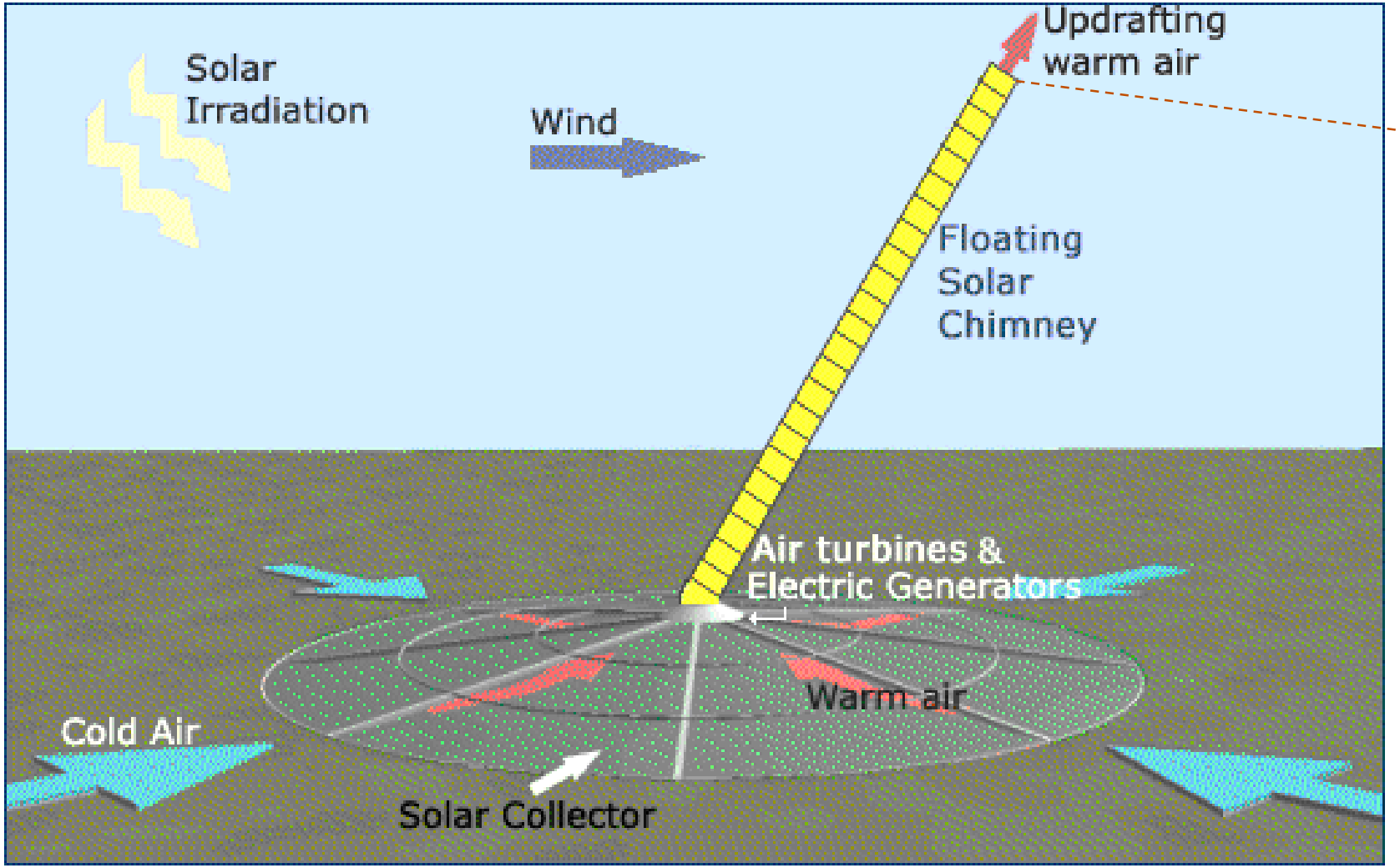
Improvement? Floating Chimney



Chimney made out of hot-air balloon fabric with walls filled with He or similar.

Theoretically cuts down on capital cost, can reach up to 3km tall.

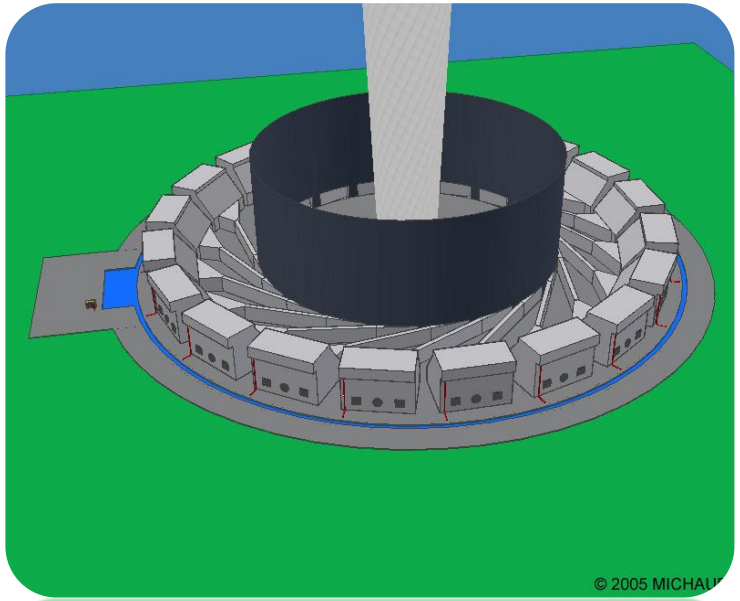
The author says that this "solves the energy crisis". I disagree.

But it might still be useful.

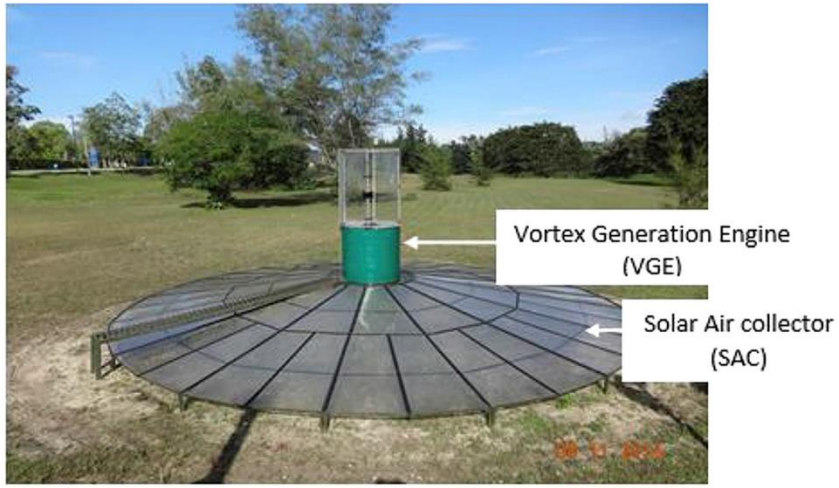
Source: Cervone et al. Design of solar chimney power plant for Meditteranean countries. International Conference on Clean Electrical Power, p 480-4, 2011
Solar Energy, ed Radu Rugescu. Chapter 10 (2010).

Atmospheric Vortex Engines

- Instead of building the 1km tower out of steel, or the 3km chimney, let's replace that with a vortex!!!
- CFD sims at Western Ontario show that it is possible. Demos built here + Malaysia



Small scale demonstration of concept.
https://www.youtube.com/watch?v=nwo4TnZy6Fs&feature=youtu.be



Experimental model of solar vortex engine (SVE) demonstrated the possibility of producing updraft air flow as artificial vortex in tornado-like manner. The VGE replaces the tall tower in the solar chimney technology where most of the invested capital is consumed.

June 2018!

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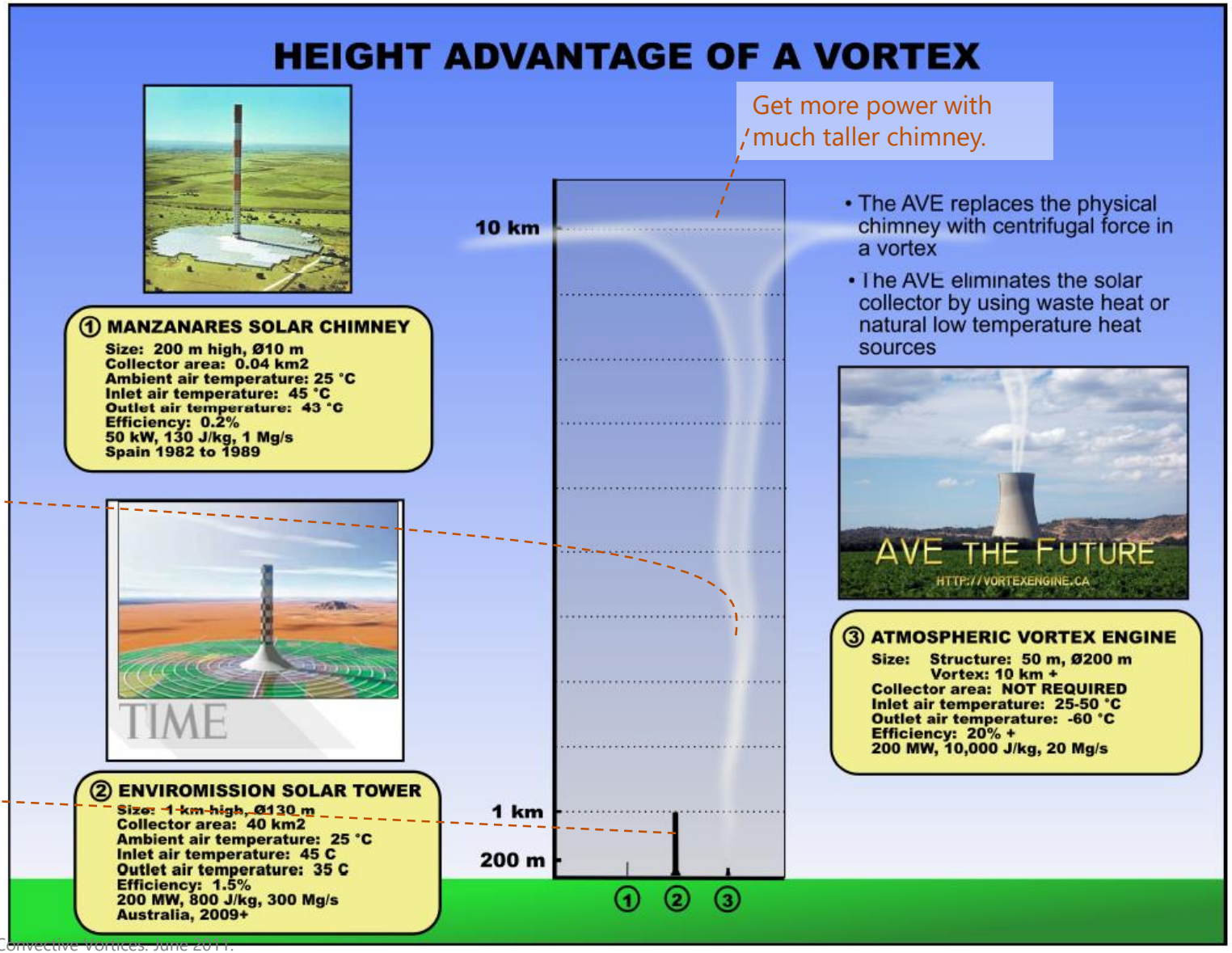
Sources: Michaud L. Harnessing energy from Convective Vortices. June 2011.
Al-Keyiem HH, Mustafa AT, Gilani SIU. *Renewable Energy* 121:389-399 (2018)

AVE: Height Advantage

Discussion:
Is this possible?
Is this crazy?
Is this practical?
Will this be affordable?
Will people be ok with this?

Spend some energy to make the vortex

Result: Produce the same power (200 MW) with 1/5 of the height (and capital cost?).



Source: Michaud L. Harnessing energy from Convective Vortices. June 2011.

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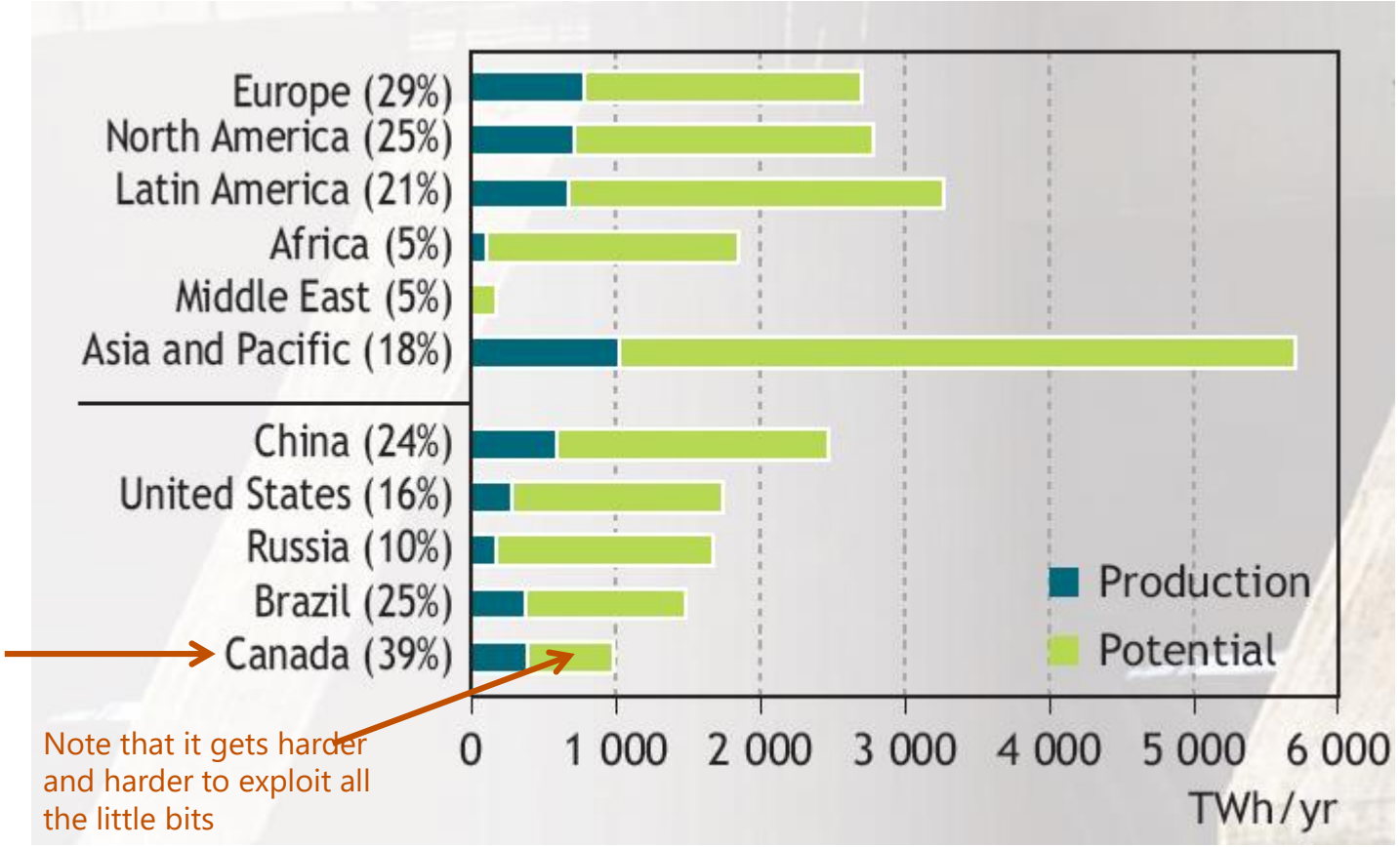
3. Hydro

Water-power, not the cute Ontario word for electricity

Hydroelectric Power

- Basically awesome, clean, renewable, and cheap.
- Takes the energy out of rivers and high elevations, but the wildlife impact has been acceptable in general in favor of the alternatives.
- 16% of global electricity production
- Most mature form of renewable energy



Source: IEA. Renewable Energy Essentials: Hydropower. 2010.

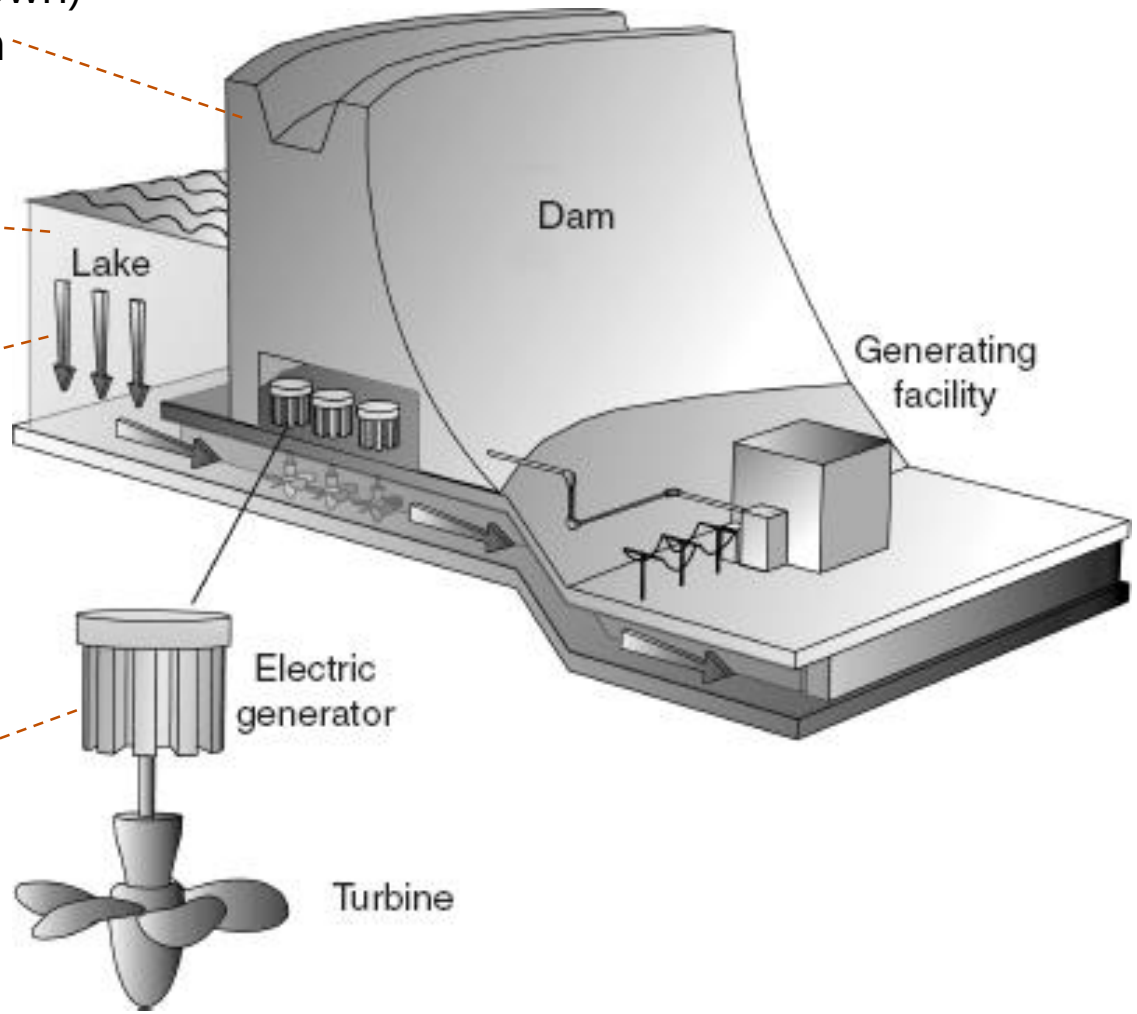
How It Works

Spillways are needed (not shown) in case water rises above dam height.

Reservoir of water builds up behind retaining wall.

Power potential directly proportional to the height of the water.

Produces AC power via a generator



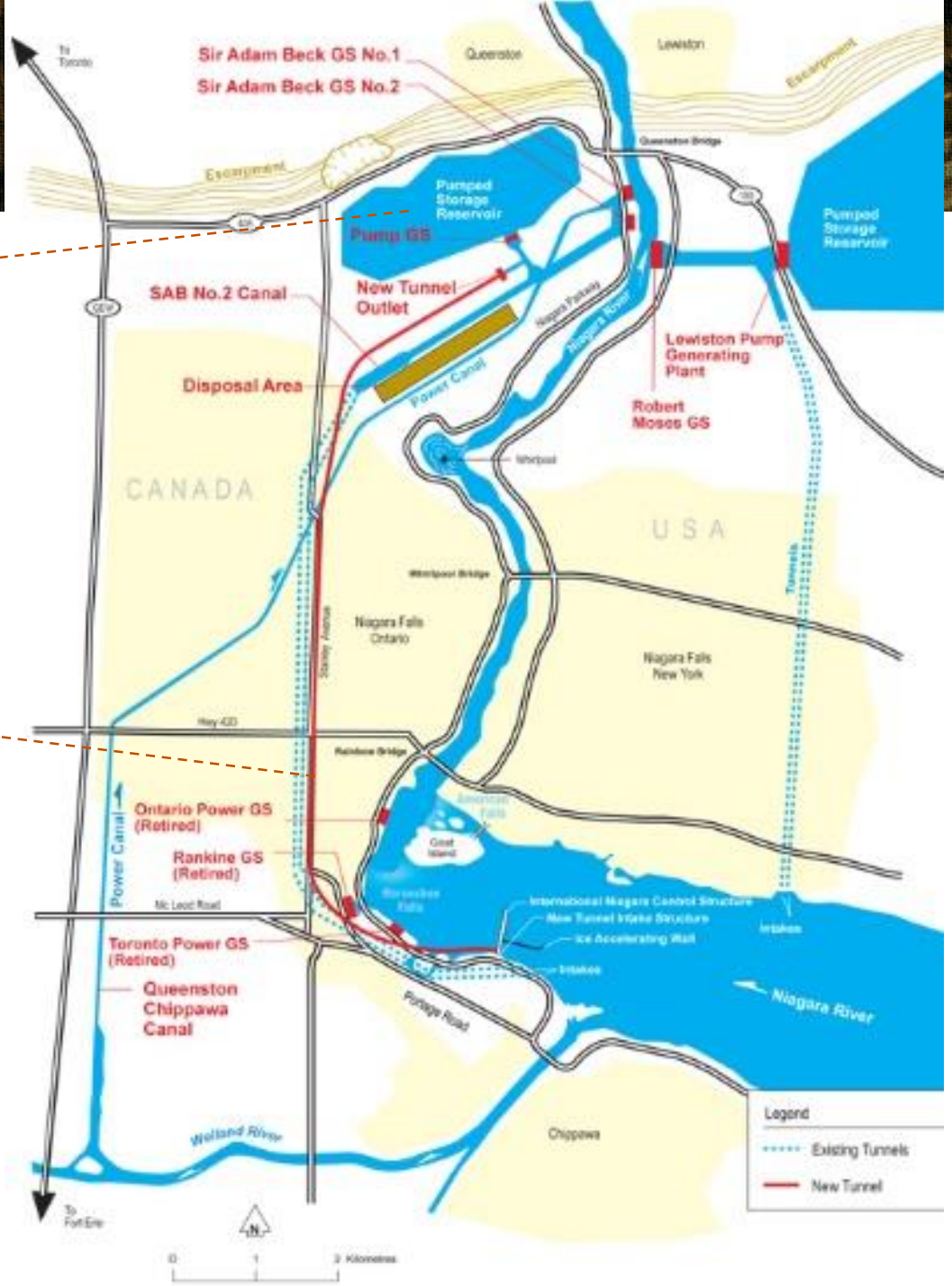
- Capital costs are $2000-4000/kW, which is relatively high.
  - Goes up as you get smaller, harder to reach, farther away, etc.
  - These costs are for the most readily technologically exploitable.
- However, lifetimes are long, so LCOE is low (5-10 ¢/kWh)

Source: Gevorkian P. Sustainable Energy Systems Engineering: The Complete Green Building Design Resource. Chapter 14

Niagara River System

Pumped Storage

Instead of putting turbines above the falls, they pull water away and around through underground tunnels.



Source: Ontario Power Generation

4. Summary

The energy mix.

Approximate US costs of new power five years from now

Discussion: Why do we not just blanket the world with wind turbines if it is going to be this cheap and has no CO_2 emissions???

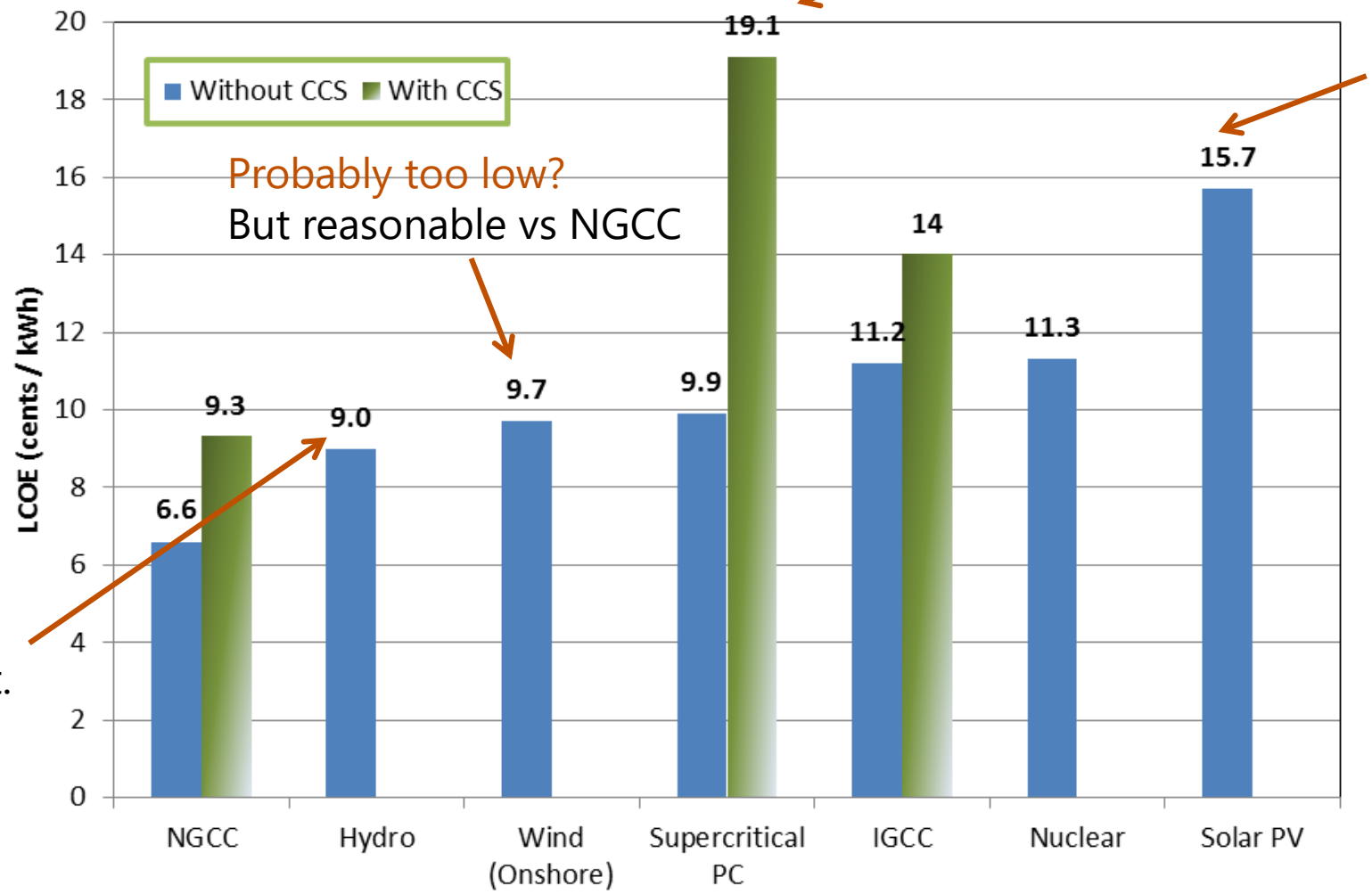
Probably too high.

Solar Thermal is double!

(Although proponents put it closer to 25)

Probably too low?
But reasonable vs NGCC

Note, for NEW hydro.
Canada doesn't have much cheap hydro left.



Source: US EIA. Annual Energy Outlook (2012). Supercritical PC is an extrapolation using relative costs in re: Bitunimous Baseline report
IEA, Concentrating Solar Power Technology Roadmap. 20107.

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