High-Efficiency, Two-Stroke Internal Combustion Engine

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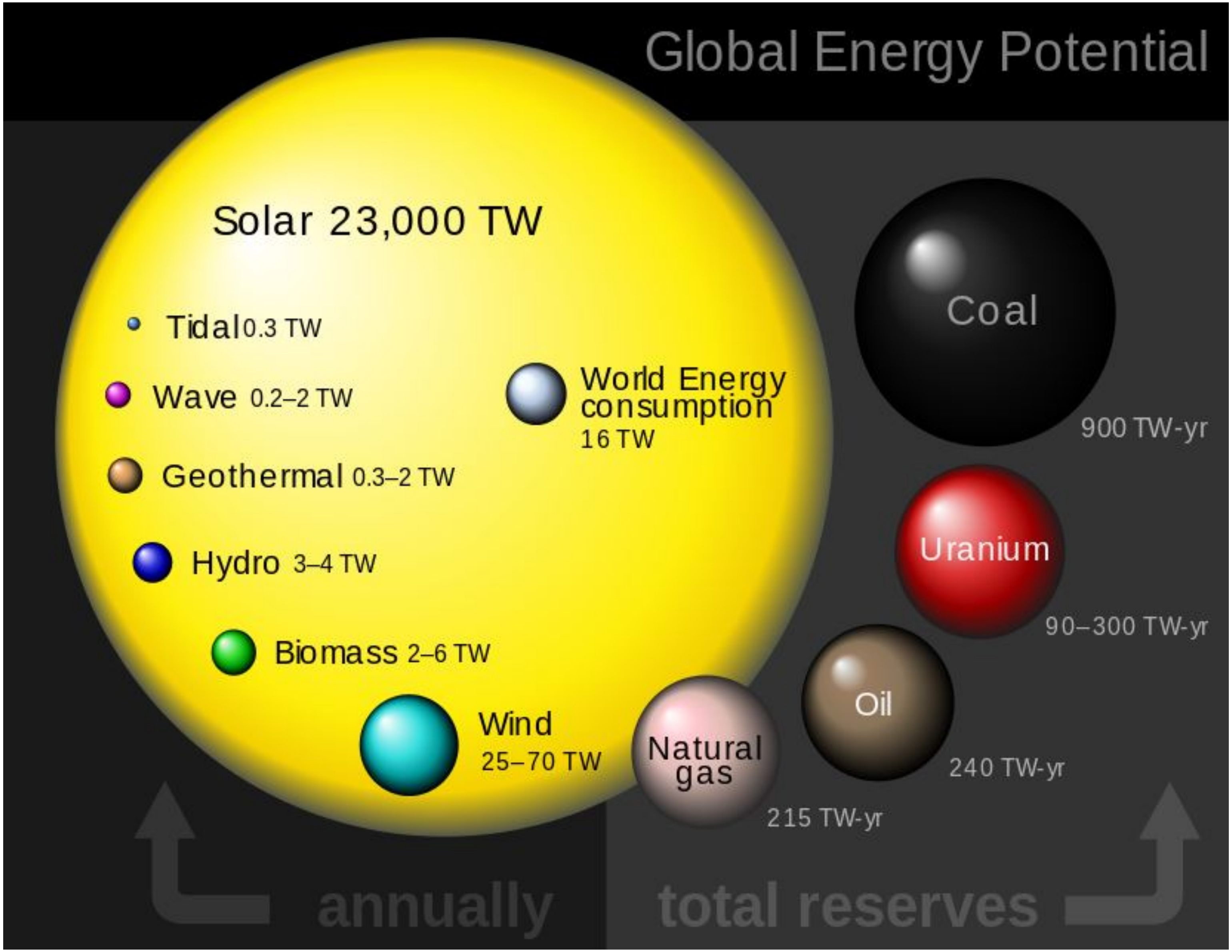
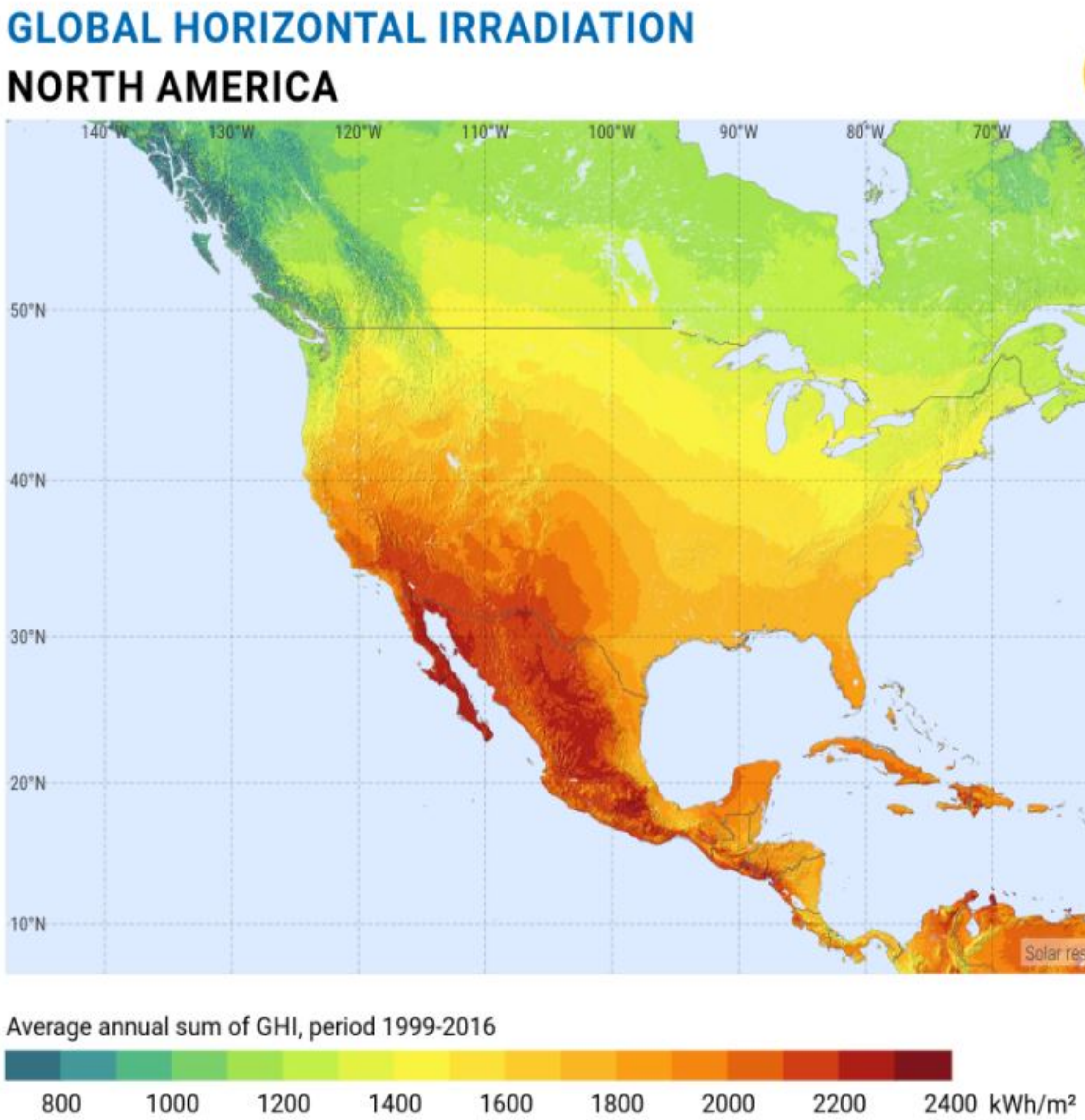
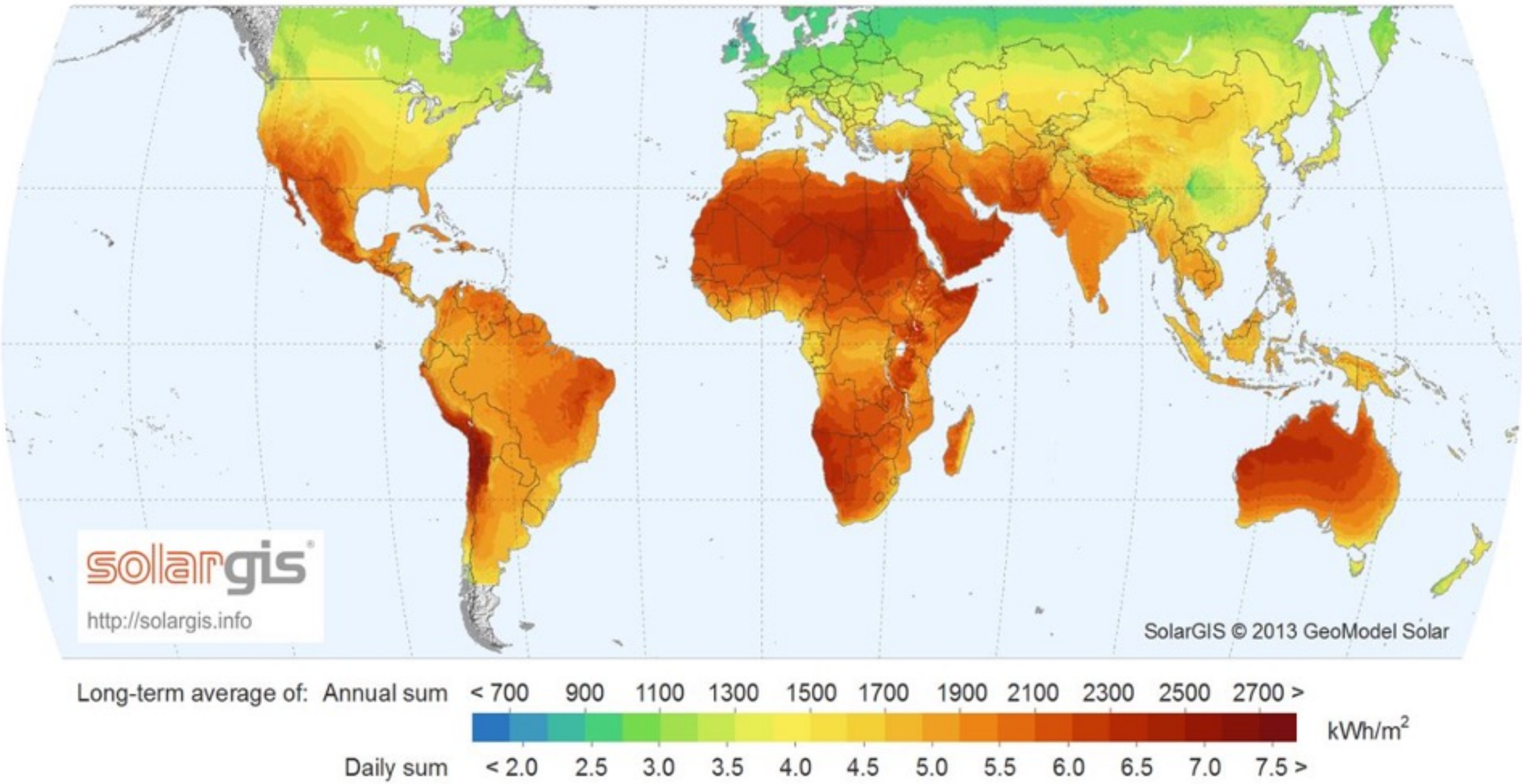


Rachel Myslivi , Climate and Energy Project, 2015

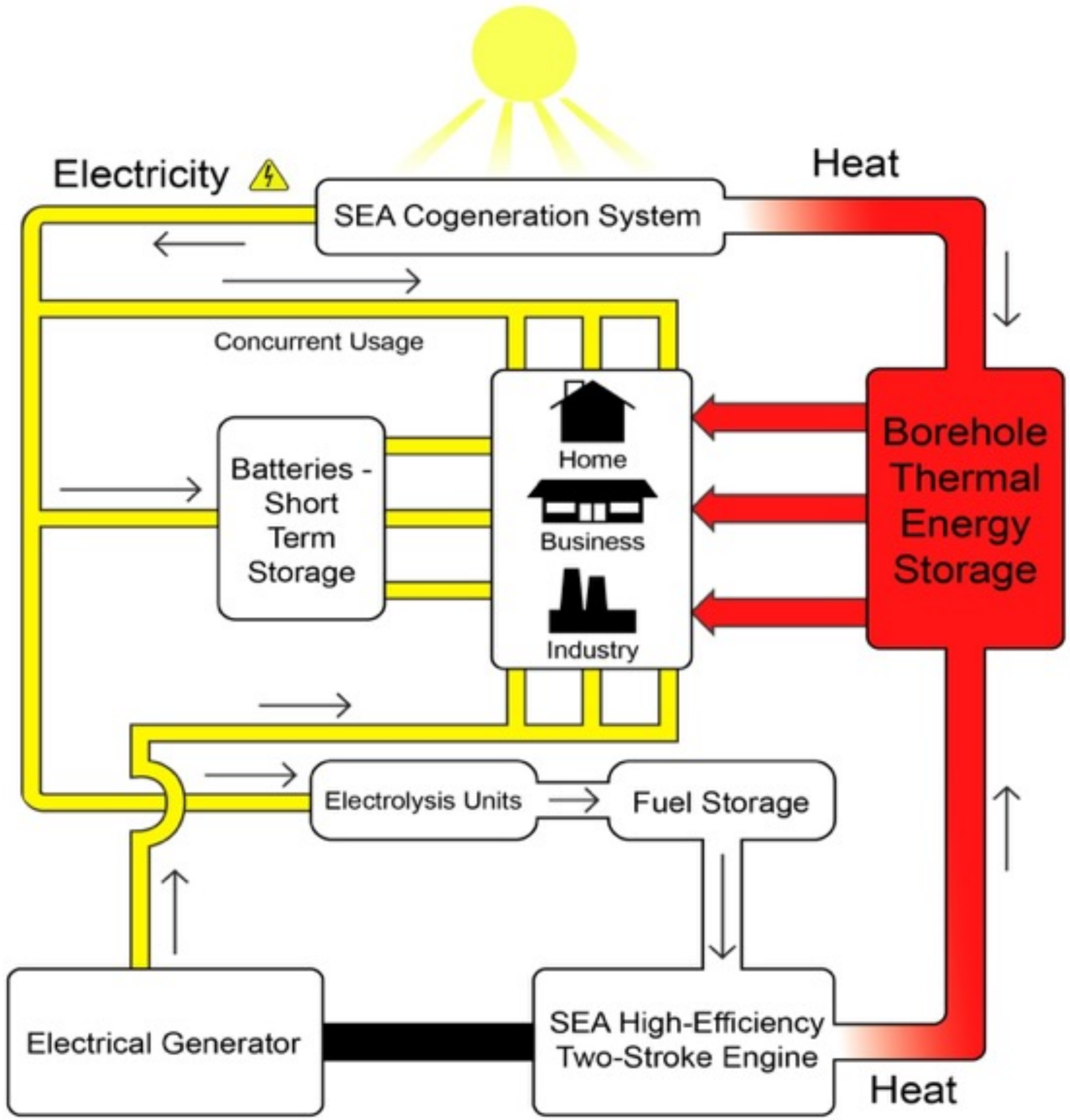

GLOBAL HORIZONTAL IRRADIATION
NORTH AMERICA
SOLARGIS
140°W
130°W
120°W
110°W
100°W
90°W
80°W
70°W
60°W
50°W
50°N
40°N
30°N
20°N
10°N
Solar resource map © 2017 Solargis
500 km
Average annual sum of GHI, period 1999-2016
800
1000
1200
1400
1600
1800
2000
2200
2400 kWh/m²

Global Horizontal irradiation



When we have cost-effective long-term (seasonal) storage for the energy forms that we derive from sunlight, solar becomes a replacement for, rather than a supplement to, other energy resources.

Collection, conversion, long-term storage … the solar value chain



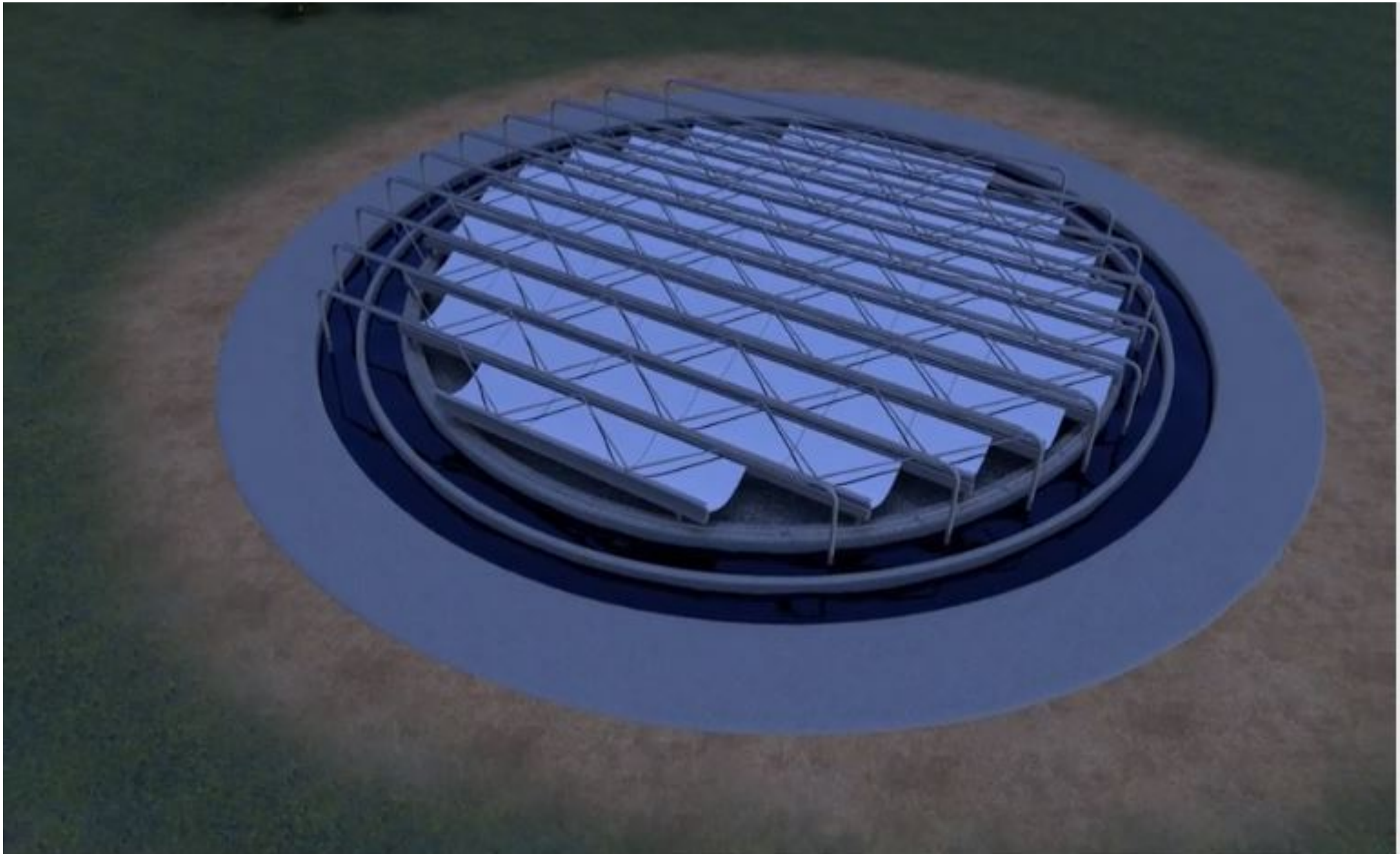
Existing CSP thermal-electric technology

NREL parabolic trough workshop (2007) …SEGS Plant

Existing CSP thermal-electric technology

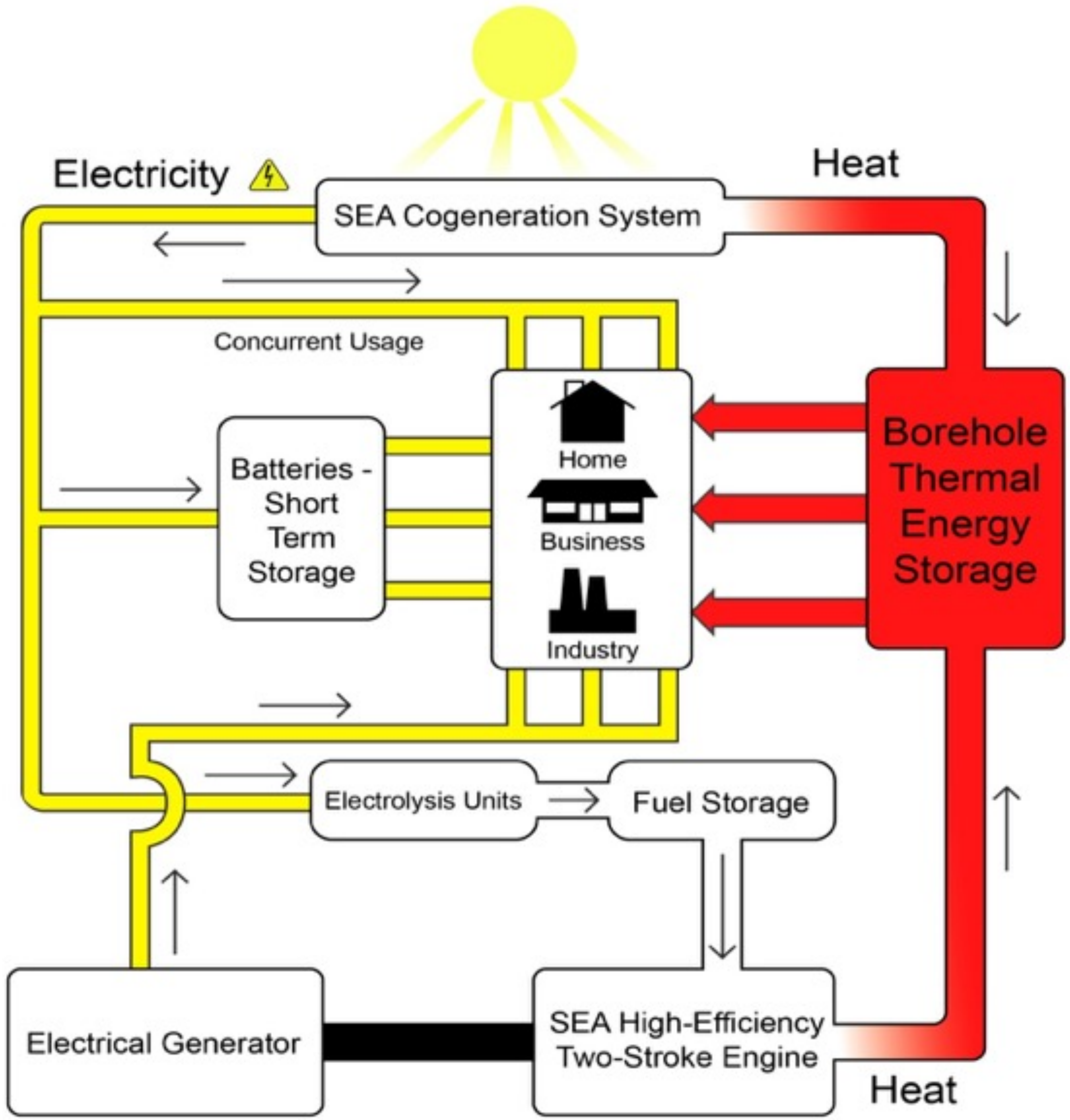
David Nunuk Photography … SEGS Plant .

Cogeneration system with azimuth angle sun tracking…electricity plus thermal



Free-Hanging Parabolic trough Reflector

Collection, conversion, long-term storage … the solar value chain

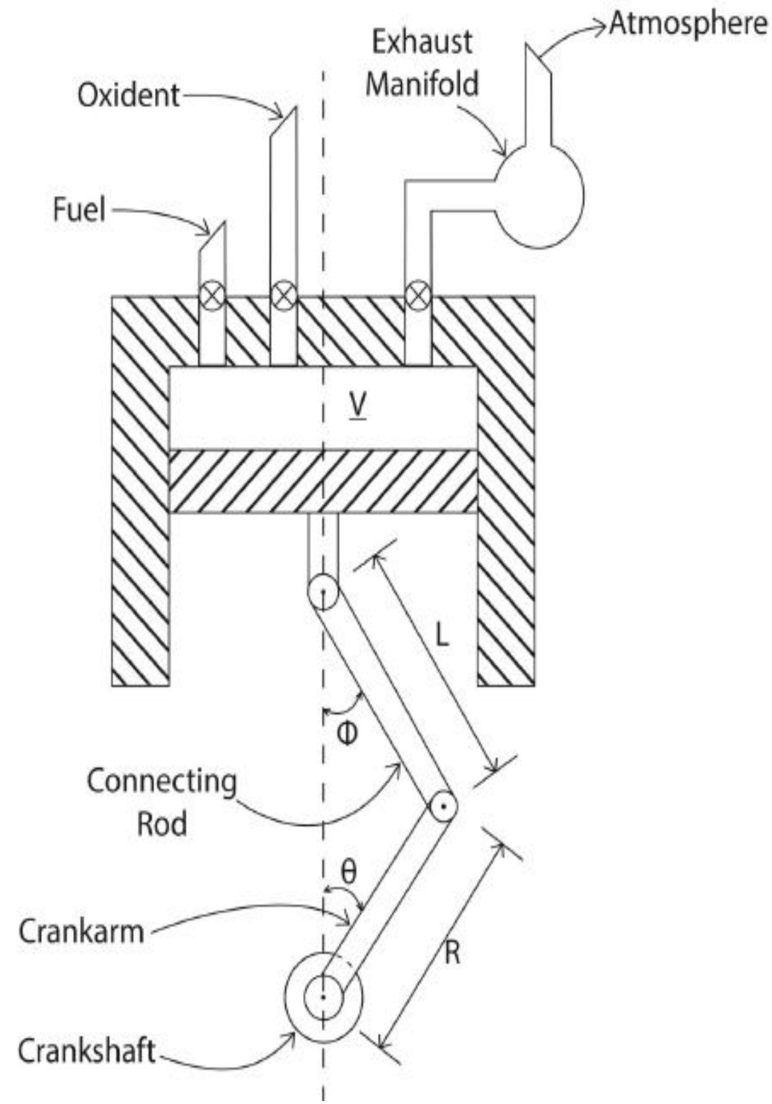


Reciprocating piston ICEs have inherent advantages over fuel cells

- No expensive catalysts or other special materials
- Remarkably immune to fuel and oxidant impurities
- Easy recovery (not disposal) of “waste heat”
- Quick response to load changes
- Efficiency relatively independent of size
- Mechanically and thermally simple devices, and they are reliable, low-maintenance, and they have long operating lifetimes.
- We already build them in large numbers, we know how to build them inexpensively, and we can build them in any size we need, even above 100,000 HP.

High efficiency two-stroke engine

- Pure power stroke
- Pure exhaust stroke
- No compression stroke
- No internal work during exhaust stroke
- Near-zero clearance volume
- Fuel and oxidant gases are injected during initial part of power stroke
- Expansion ratio (related to efficiency) depends only on ignition angle

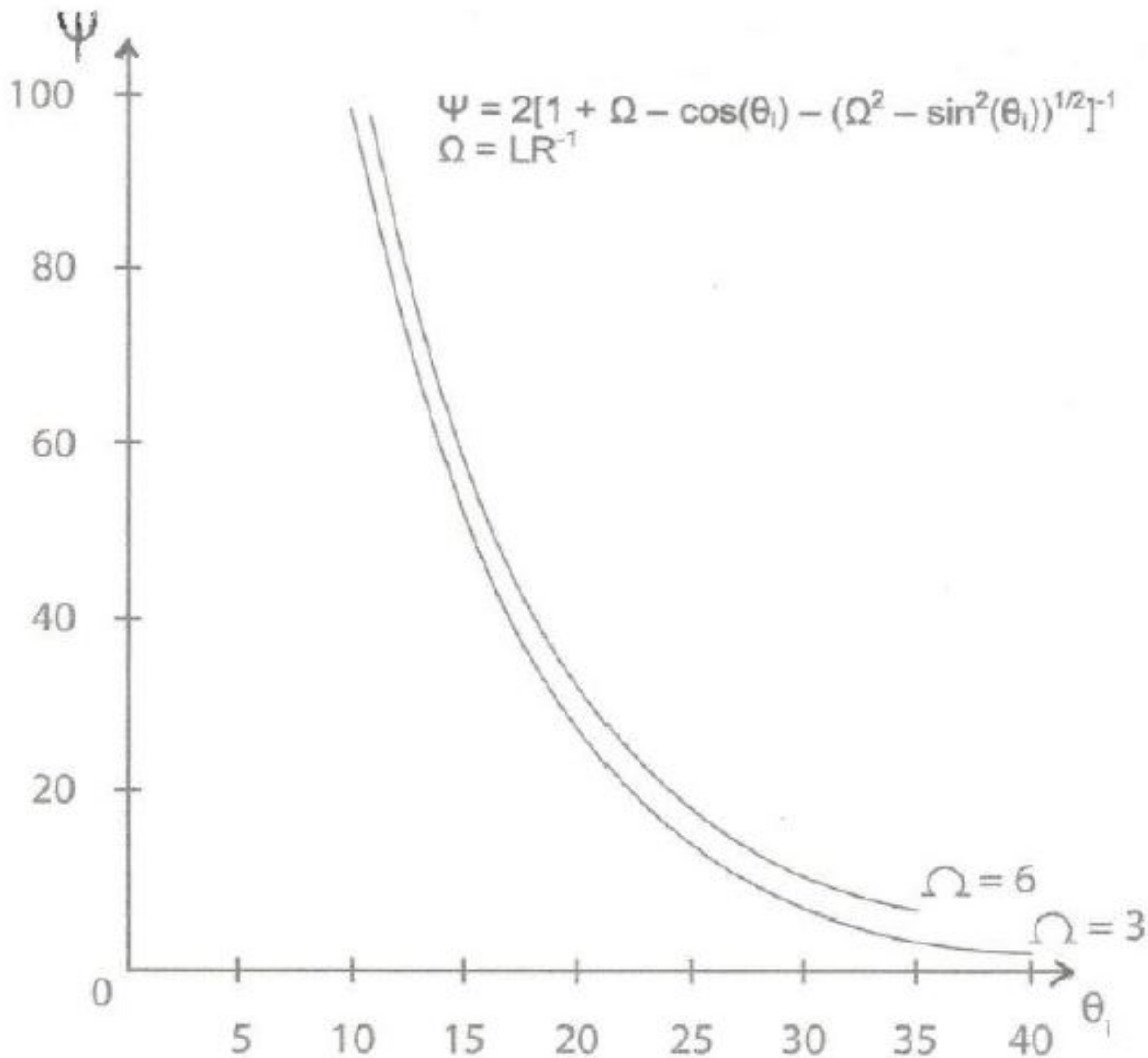


Expansion Ratio (Ψ) as a function of rod ratio (Ω) and ignition angle (θ_i):

$$\Psi = \frac{2}{1 + \Omega - \cos(\theta_i) - \sqrt{\Omega^2 - \sin^2(\theta_i)}}$$

For a given rod ratio (engine geometry) expansion ratio depends only on ignition angle, which is electronically selectable

Expansion ratio versus ignition angle for 2 values of rod ratio



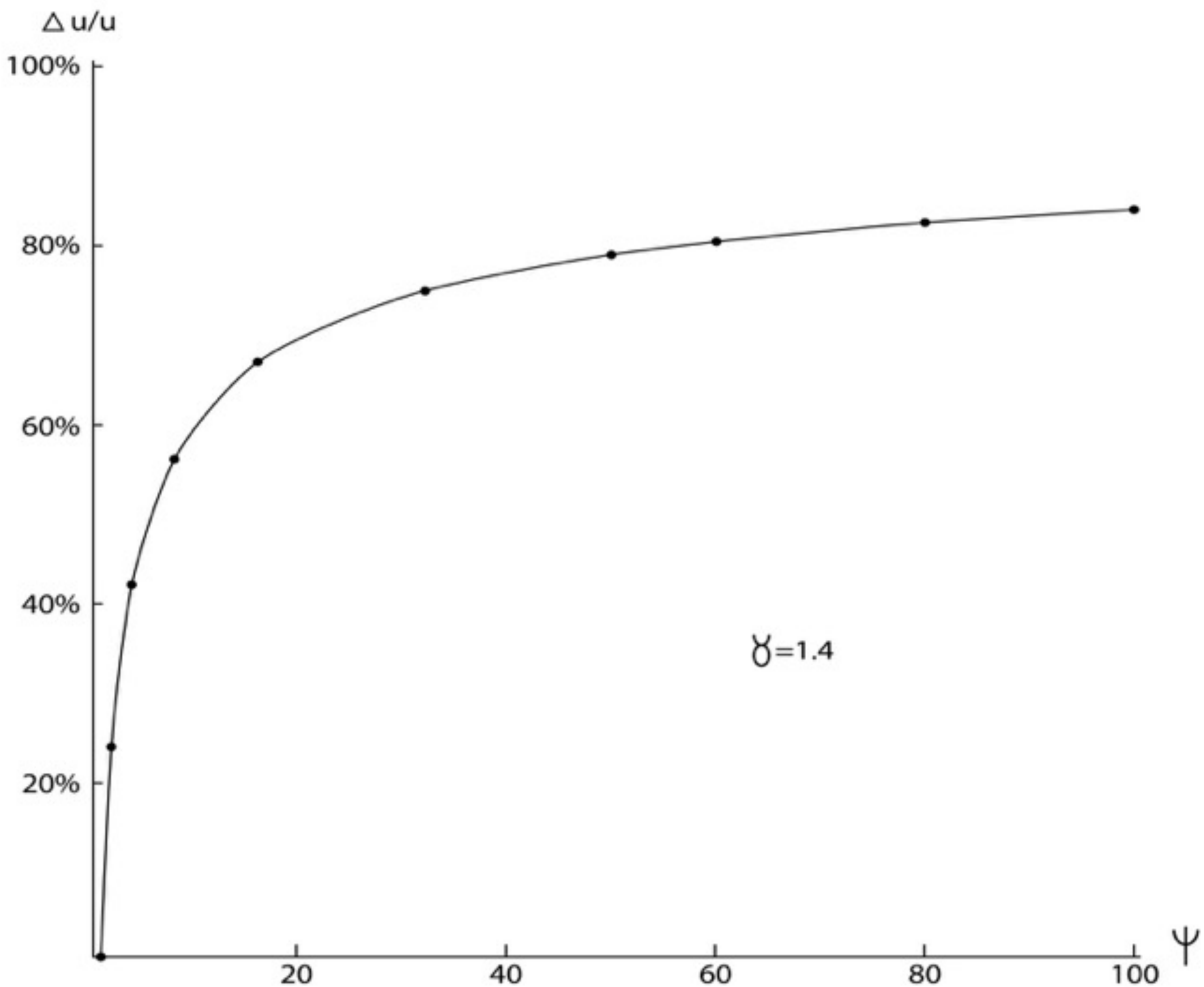
With respect to engine efficiency, larger expansion ratios are better, but there is a point of diminishing returns.

Let $T_{i,f}$ and $U_{i,f}$ be the initial and final temperatures and initial and final values of internal energy, respectively, for an ideal gas as it expands adiabatically. Assume that

$$U_{i,f} = kT_{i,f}$$

This is the same as assuming that c_v is constant with respect to temperature and that the internal energy of an ideal gas is zero at absolute zero. Then:

$$1 - \psi^{(1-\gamma)} = (T_i - T_f)/T_i \approx (U_i - U_f)/U_i = \Delta U/U_i$$



Δ u/u
100%
80%
60%
40%
20%
ɣ=1.4
20
40
60
80
100
Ψ

Change in internal energy, ΔU, and shaft work, W_s

In an adiabatic expansion, ΔU, the change internal energy of the combustion products, is equal to the work done by the combustion gases on the piston.

However, not all of that work is done on the crankshaft because the piston also pushes against atmospheric pressure as the combustion gases expand.

Change in internal energy, ΔU, and shaft work, W_s

$$W_s = \Delta U - P_A(V_f - V_i)$$

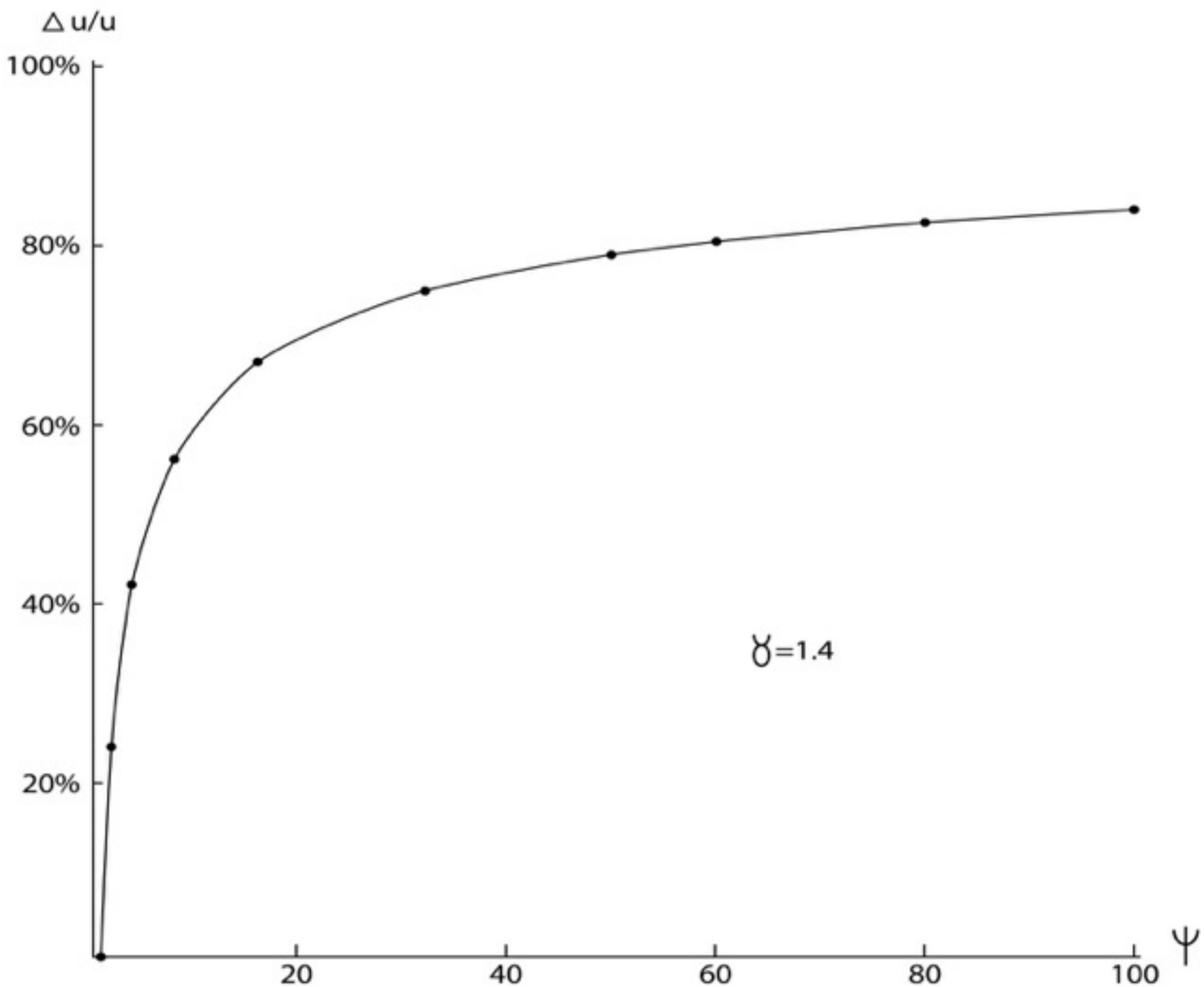
The importance of the second term is reduced by pressurizing (increasing the molar specific volume) of the fuel and/or oxidant gases prior to combustion, usually by a compression process which also produces gas heating.

In the present engine, the fuel/oxidant gases are at room temperature when they enter the combustion chamber, allowing conditions of molar specific volume that cannot be achieved by compression.

The initial internal energy of the combustion products before expansion, U_i is comprised of two parts.

- **Let's say we have the combustion products and the inert oxidant gases and unburned fuel gases at room temperature. They have an internal energy U_0.**
- **Let's say we now heat these room temperature gases by adding the combustion energy of the fuel, E_F. Then we have:**

$$U_i = U_0 + E_F \text{ and } E_F = U_i - U_0$$


Δ u/u
100%
80%
60%
40%
20%
ɣ=1.4
20
40
60
80
100
Ψ

Real engines are not as efficient as shown in the figure because the processes involved are not adiabatic

- **Thermal energy is lost from the combustion chamber by conduction through the cylinder walls and the piston head.**
- **Thermal energy is lost through mass flow as the warm exhaust gases are forced out of the combustion chamber into the atmosphere.**
- **Minimizing these losses, that is, making the expansion process more nearly adiabatic, helps to move closer to the ideal curve.**

Approaching adiabatic expansion

- Conduction losses are reduced because the initial temperature of the combustion products is relatively low (no compression process), and because ignition is delayed until well after top-dead-center (piston moving more rapidly when combustion products are formed).

- Mass flow losses are reduced by providing a large expansion ratio for the combustion products (cooler gases in the exhaust).

Summary

- Dimensions, interconnection, and mechanical layout of the engine's components produce near-zero clearance volume.
- Engine accepts pressurized fuel and oxidant gases at approximately room temperature during the power stroke
- Ignition of fuel/oxidant gases is delayed relative to top-dead-center, but large expansion ratios are still possible because of near-zero clearance volume.
- Expansion ratio and torque are determined by choice of ignition angle. Efficiency and torque can be balanced for any given application.

Summary (Continued)

- Pre-combustion fuel and oxidant temperatures are lower than in an engine with a compression cycle, so the peak temperatures of combustion products are also lower, thereby reducing thermal energy losses through the cylinder walls during the power stroke.
- The piston is moving at a considerable velocity when fuel and oxidant gasses are ignited. The temperature of the combustion products drop more quickly and this also reduces thermal energy losses during the power stroke.

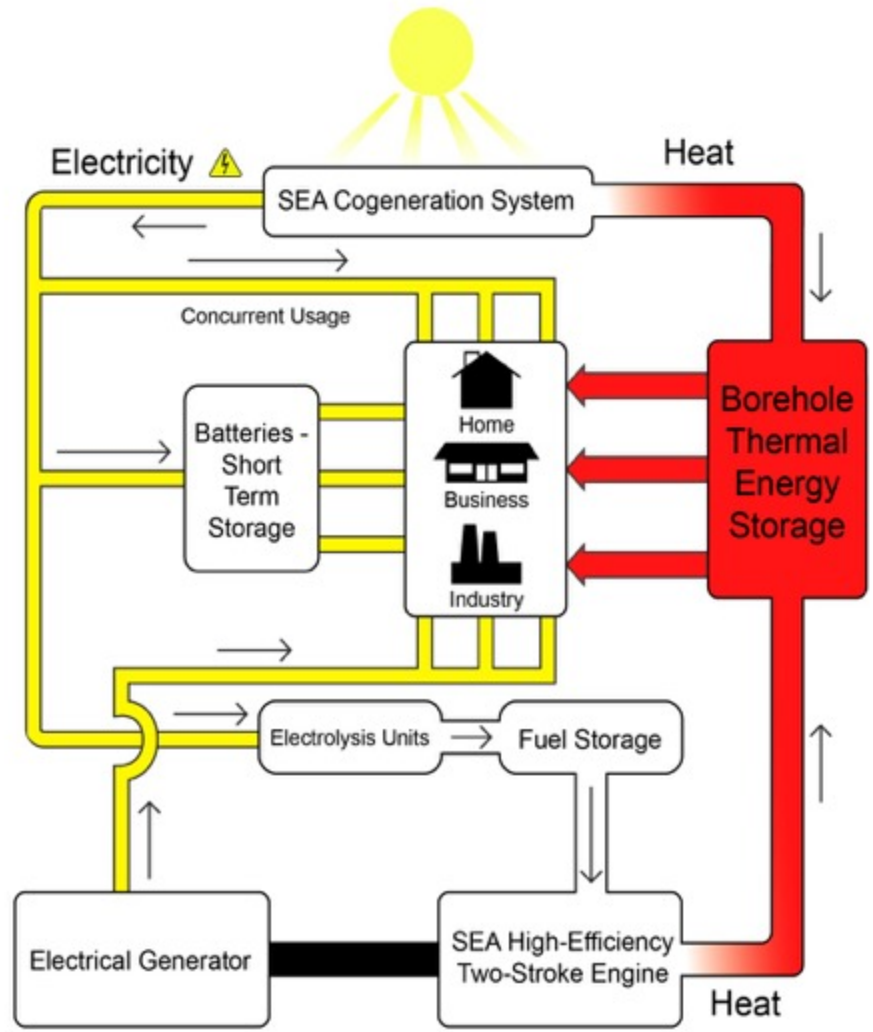
Summary (continued)

- **A large expansion ratio for the combustion products reduces thermal energy losses in the exhaust gases.**

- **The fact that fuel and oxidant gases enter the combustion chamber at room temperature allows pre-combustion conditions of molar specific volume that cannot be created by compression.**

What does it all mean?

- We don’t need new technology developments or scientific breakthroughs We just need to integrate technologies that we already have.
- Solar becomes <u>the</u> primary energy resource, no duplicated capacity from other energy resources
- Complete decentralization of all energy industries
- Millions of jobs at the local level



Questions?

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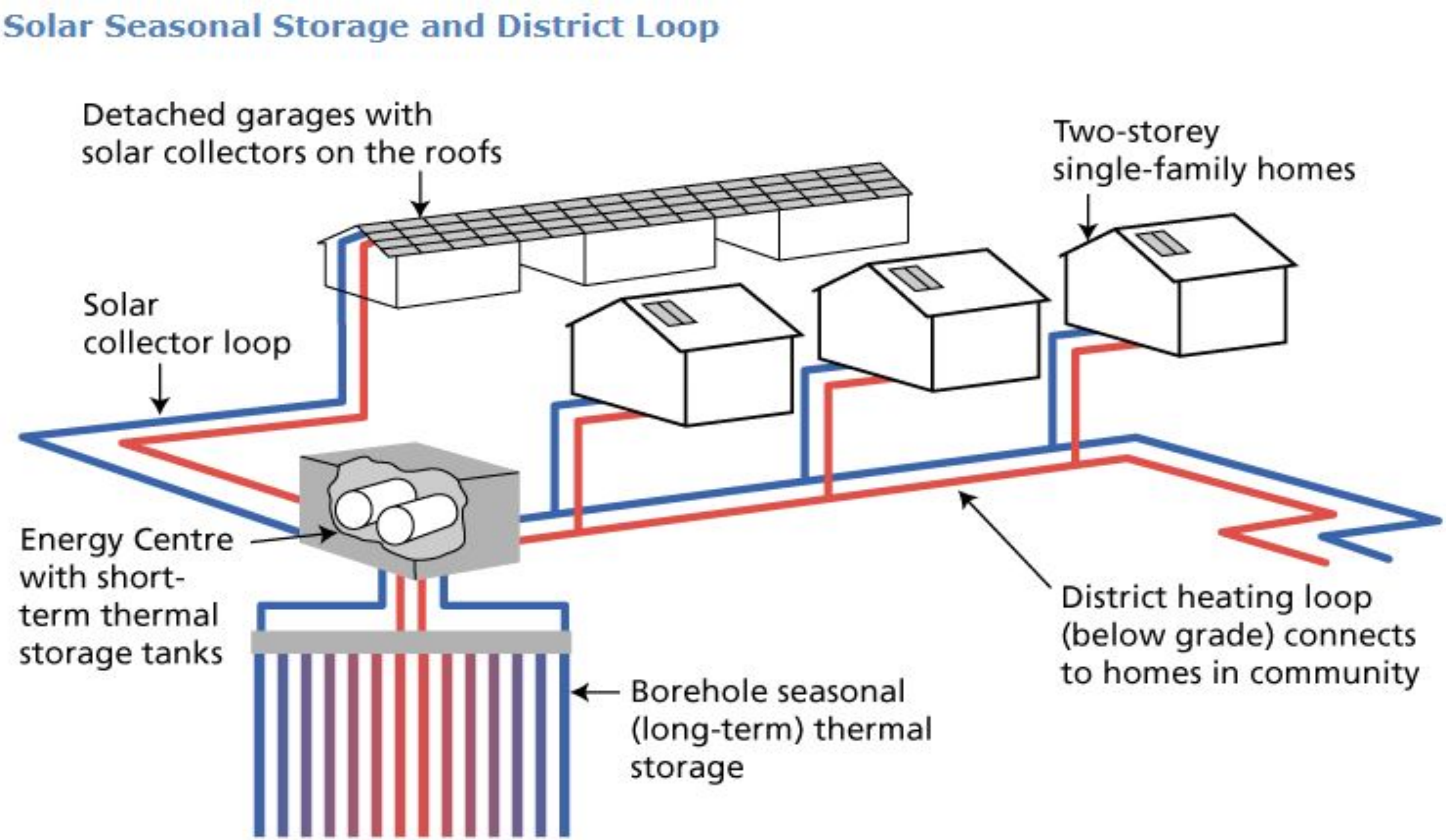
Seasonal thermal energy storage

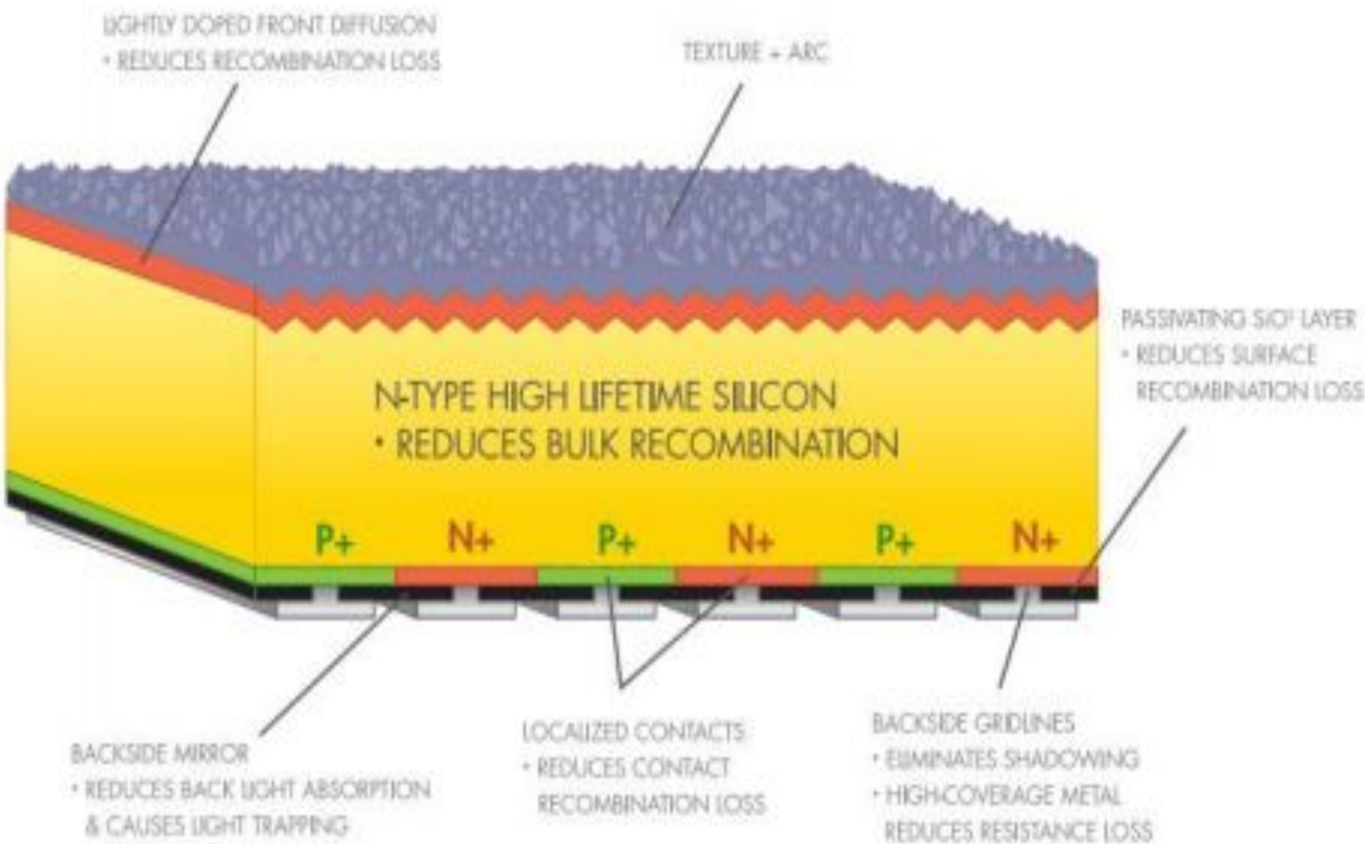


Drake Landing Solar Community, Alberta, Canada

Borehole seasonal thermal energy

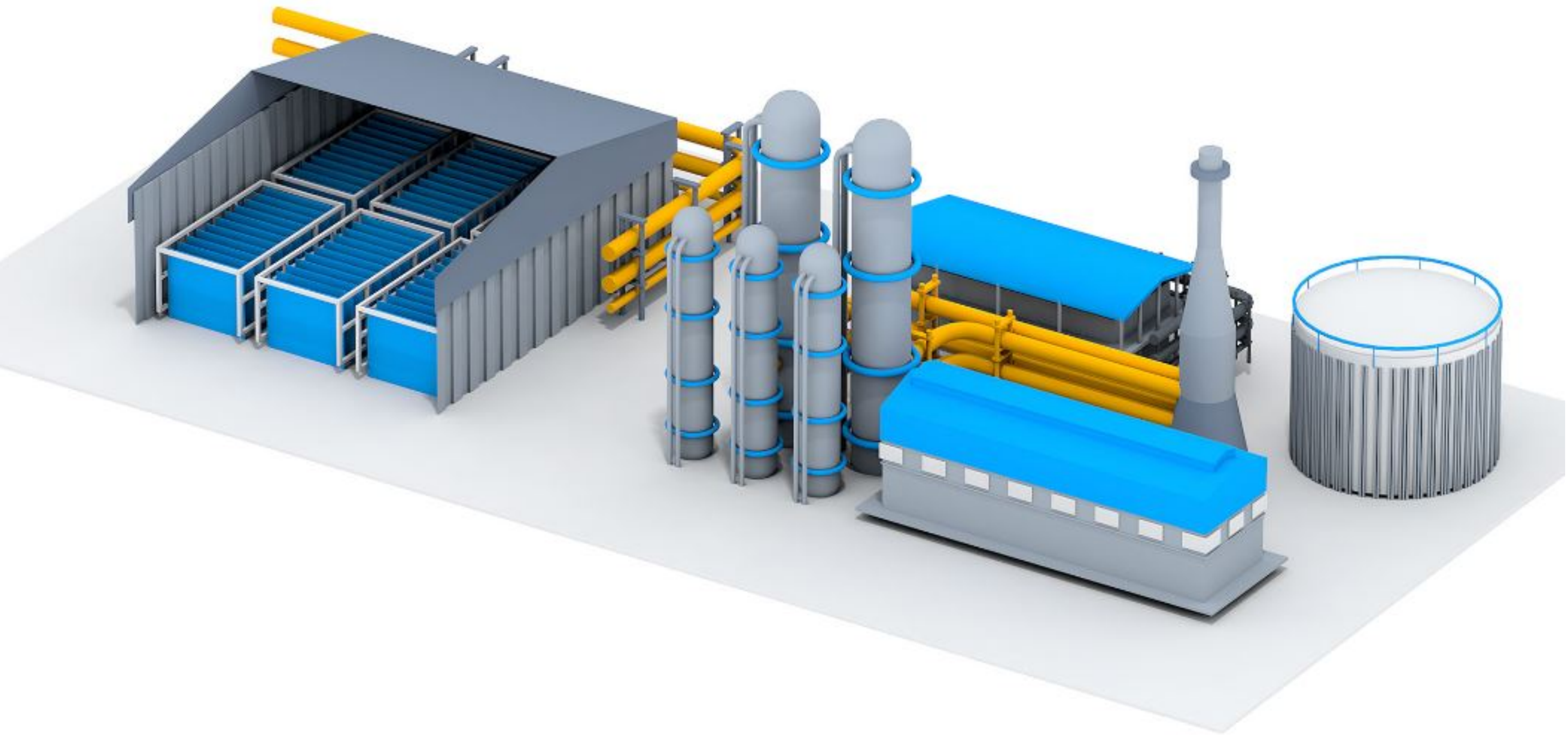
Drake Landing Solar Community, Alberta, Canada

Back-contact single crystal silicon cell



SunPower Maxeon cell schematic

Thyssenkrupp green ammonia plant



Thyssenkrupp AG

Wartsila-Sulzer RTA96-C – 110,000 HP

Photo provided by gcaptain (gcaqptian.com)