

Looking Forward: Solar Market 2040

Energy Needs and Technologies

*Exceptional service
in the national interest*



Clifford K. Ho
Sandia National Laboratories
Concentrating Solar Technologies Dept.
Albuquerque, New Mexico
ckho@sandia.gov, (505) 844-2384

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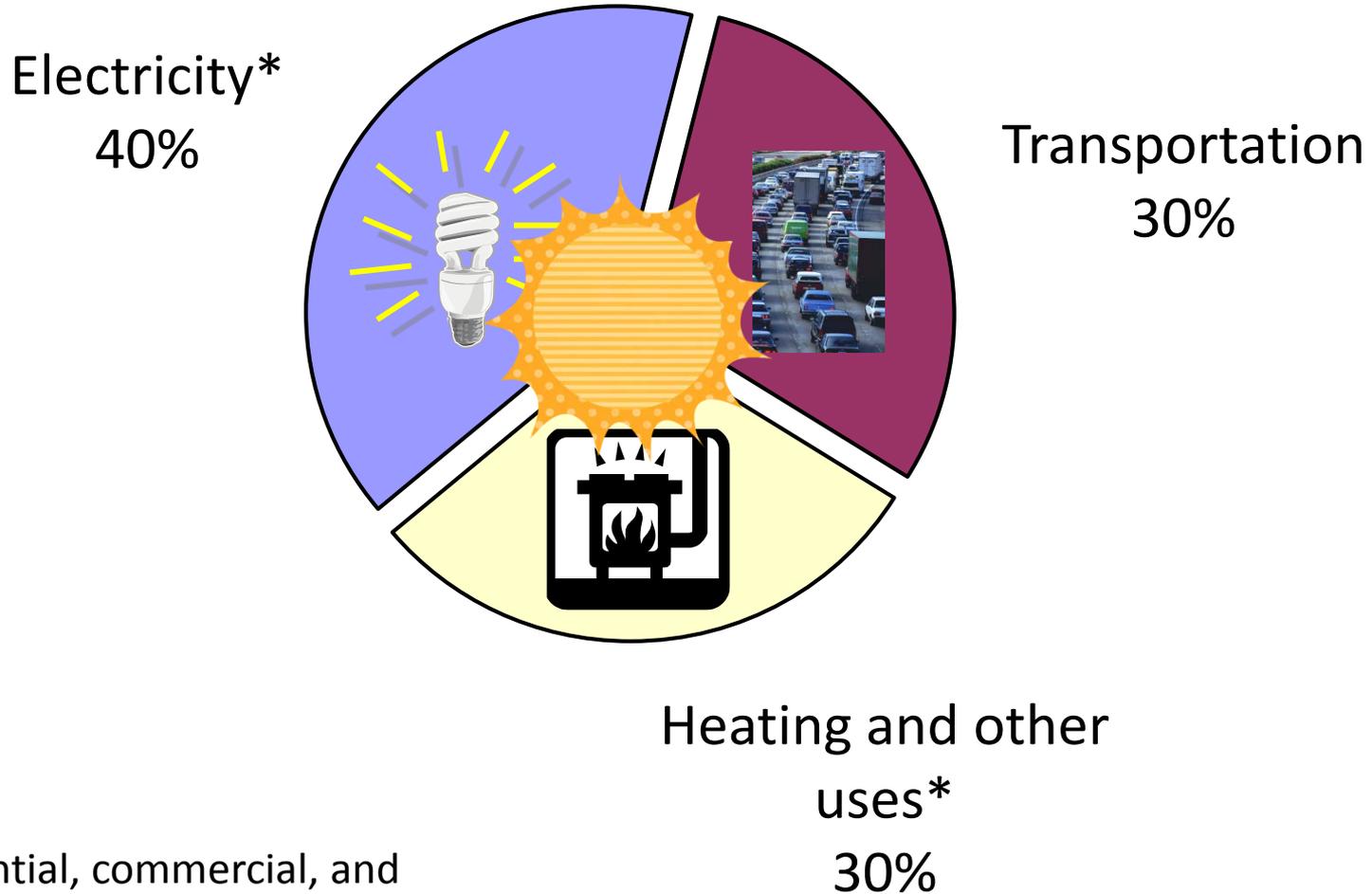


Outline

- What are our primary energy needs?
 - Current solar technologies
- Future solar technologies and applications
 - Combined power, heating, and storage
 - Transportation
- Integration
 - Multiple scales and technologies for Smart Buildings and Cities

U.S. Energy Consumption

(Adapted from Energy Information Administration, Annual Energy Review 2012)



*residential, commercial, and industrial processes

Solar Energy – Electricity Production

U.S. capacity in 2013 (Wikipedia, www.nrel.gov)

Photovoltaics (>10 GW)

Rooftop/Distributed



Utility-Scale



290 MW Agua Caliente Solar Project, Yuma County, AZ

Concentrating Solar Power (>1 GW)



390 MW Ivanpah
Solar Electric
Generating System,
CA

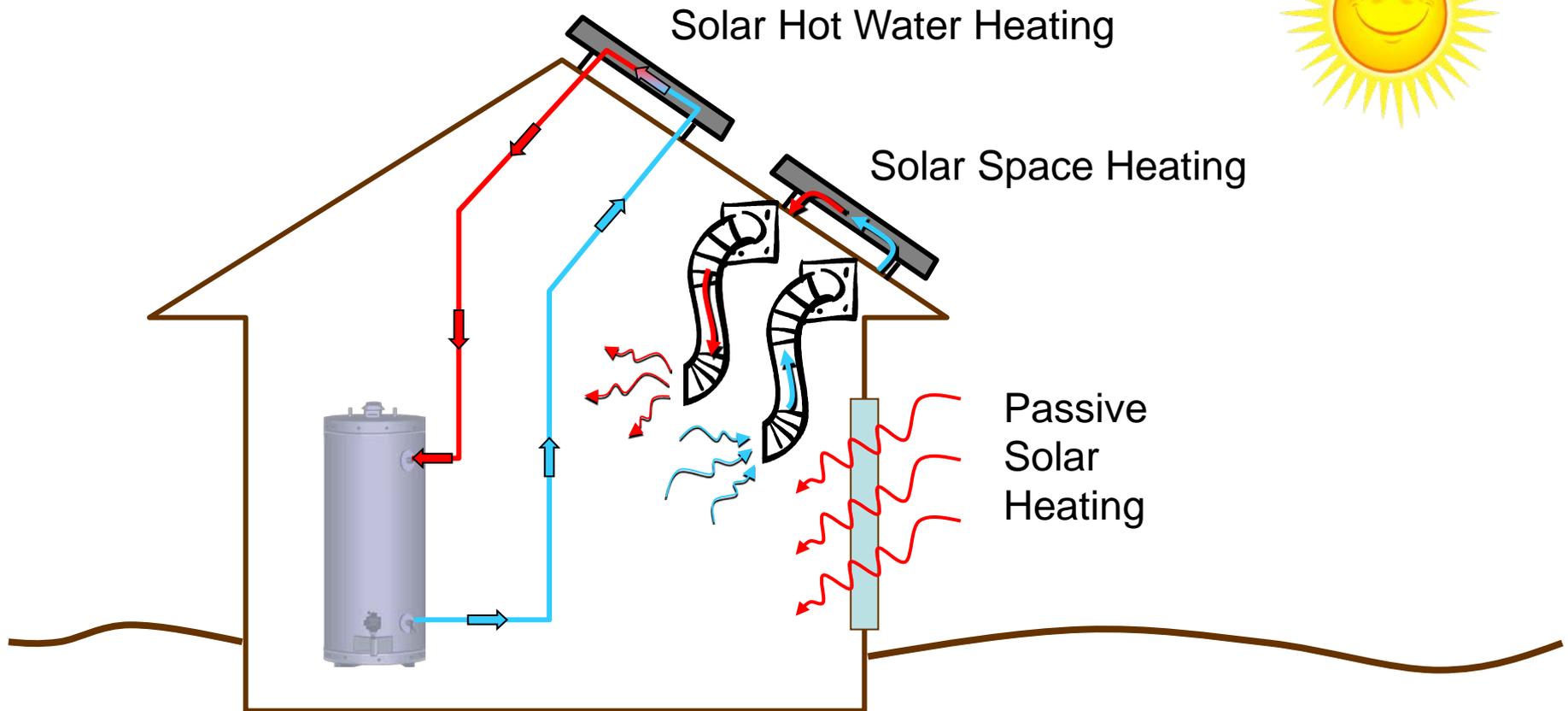
354 MW Solar Energy
Generating Systems
(SEGS I – IX), CA



280 MW Solana
Parabolic Trough Plant
with 6 hours storage,
Gila Bend, AZ

<1% of total U.S. electricity generation

Solar Energy - Heating



Vast majority of heating in U.S. comes from natural gas

Solar Energy – Transportation

(Adapted from Energy Information Administration, www.eia.gov, 2012)

- Transportation fuels
 - 93% - petroleum fuels
 - 4% - biofuels
 - 3% - natural gas
 - < 1% - electricity
 - < 1% of electricity generated from solar
 - Charging takes 4 – 8 hours using 240-volt outlet



<http://www.green-parking.co.uk>

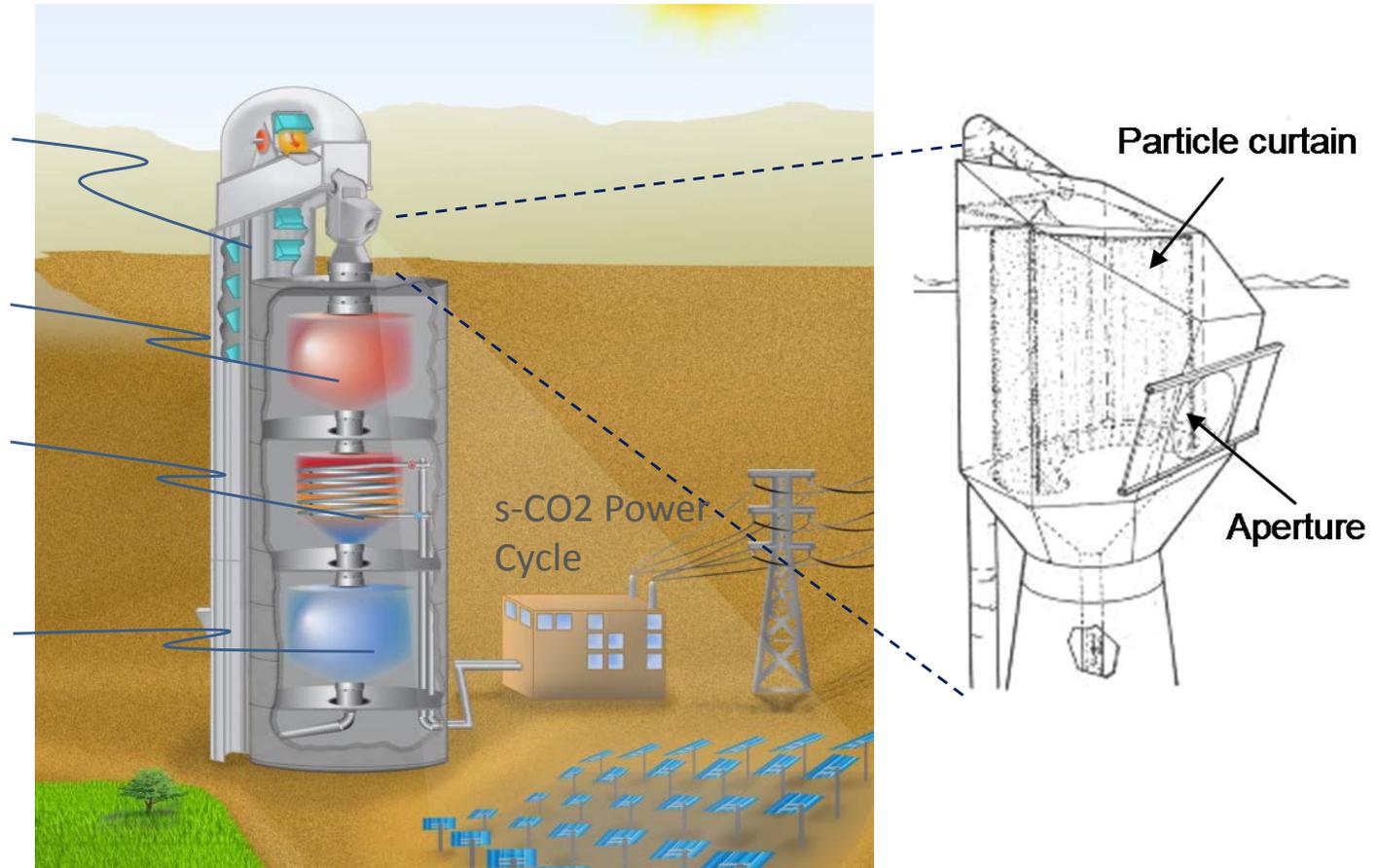
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Baseload Concentrating Solar Plant

Combined power, heating, and storage

- Dispatchable energy and heat
- Higher temperatures yield higher efficiency, lower storage cost, and grid parity

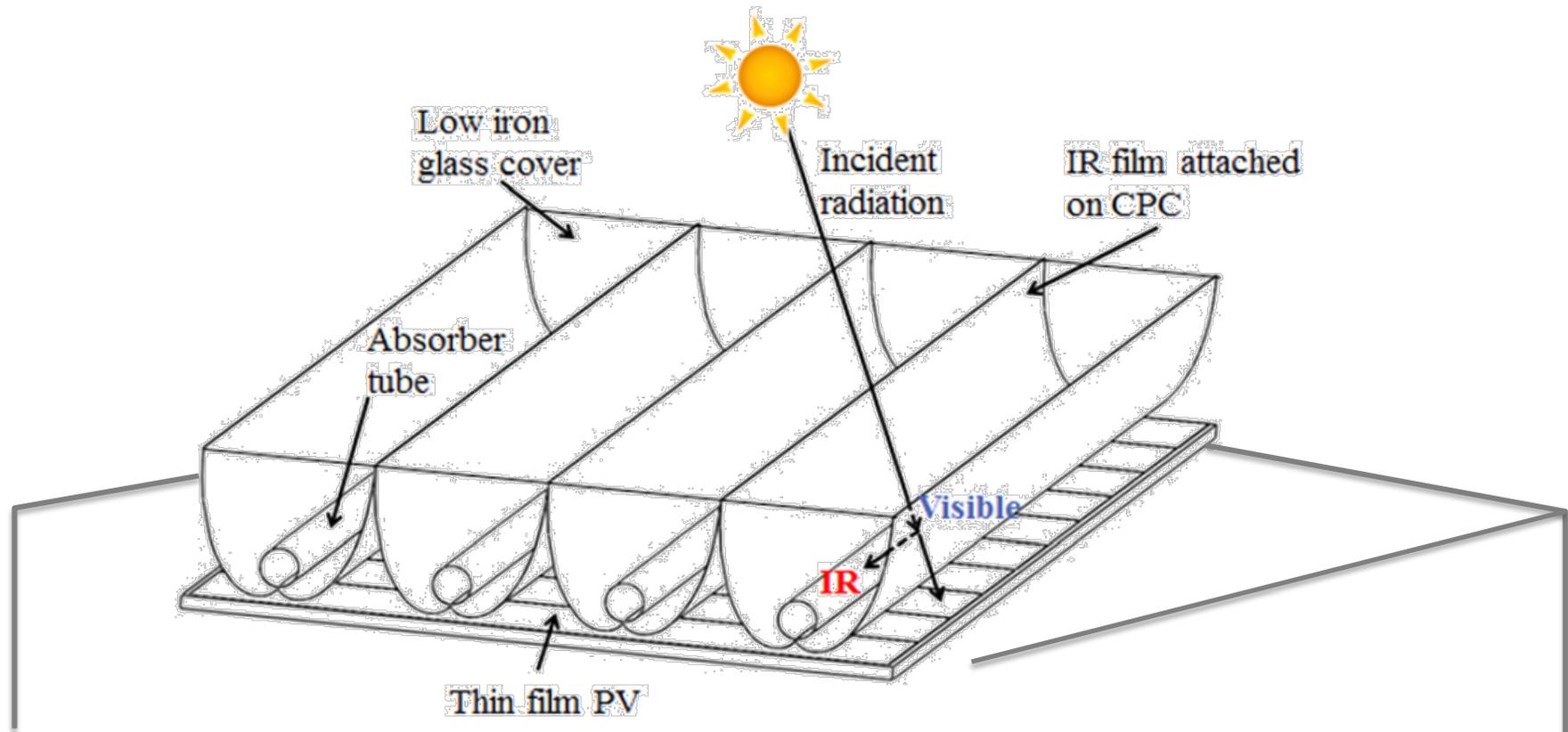


Ho et al., 2013, ASME ES-FuelCell2013-18236

Hybrid PV/CSP Systems

Combined power, heating, and storage

- Selective wavelength mirrors reflect IR while transmitting or absorbing visible for PV (*Ulavi et al., 2014; ARPA-E FOCUS FOA*)
- Concentrating PV cells integrated with thermal collectors (*ARPA-E FOCUS*)

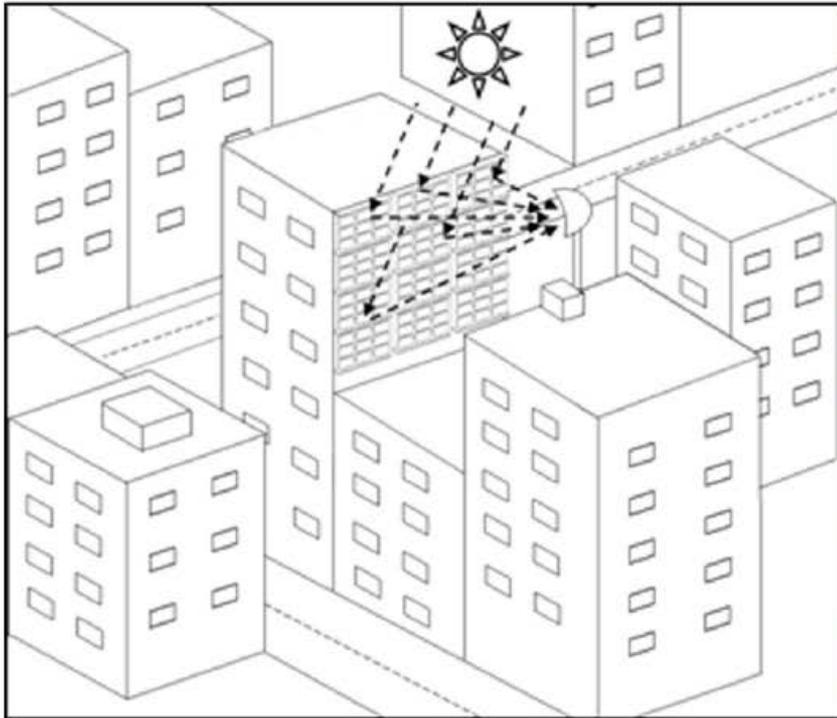


Ulavi et al., *J. Solar Energy Engr.*, 136 (2014)

Building Integrated CSP

Combined power, heating, and storage

Vertical heliostat field integrated with building facade and shades



A. Gonzalez-Pardo et al., *Energy and Buildings* 76 (2014)

Building Integrated CSP

Combined power, heating, and storage

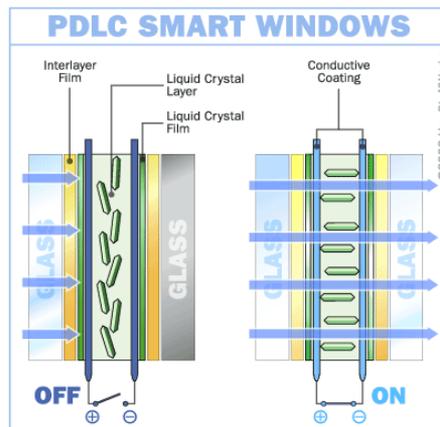
Smart windows for energy collection and storage



Tailor window properties to concentrate sunlight for hybrid PV/CSP electricity production and/or storage in buildings



<http://www.peerplus.nl>



Solar Fuels for Transportation



<http://green.autoblog.com>

Syngas

Hybrid PV/CSP Solar Fuels Charging Station

Concentrated sunlight



CO
H₂

Metal oxide catalyst

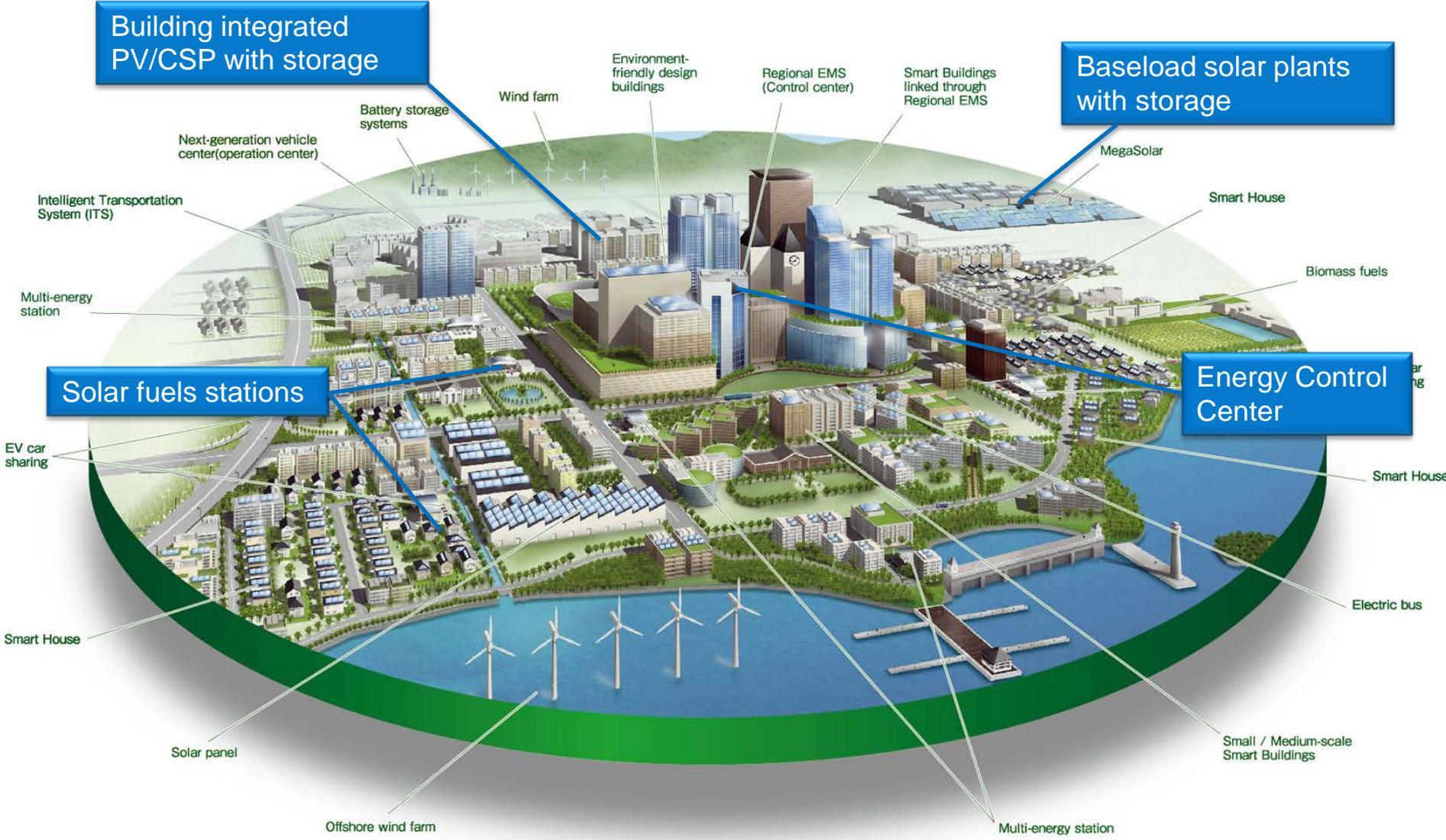
CO₂
H₂O

Thermochemical reactor

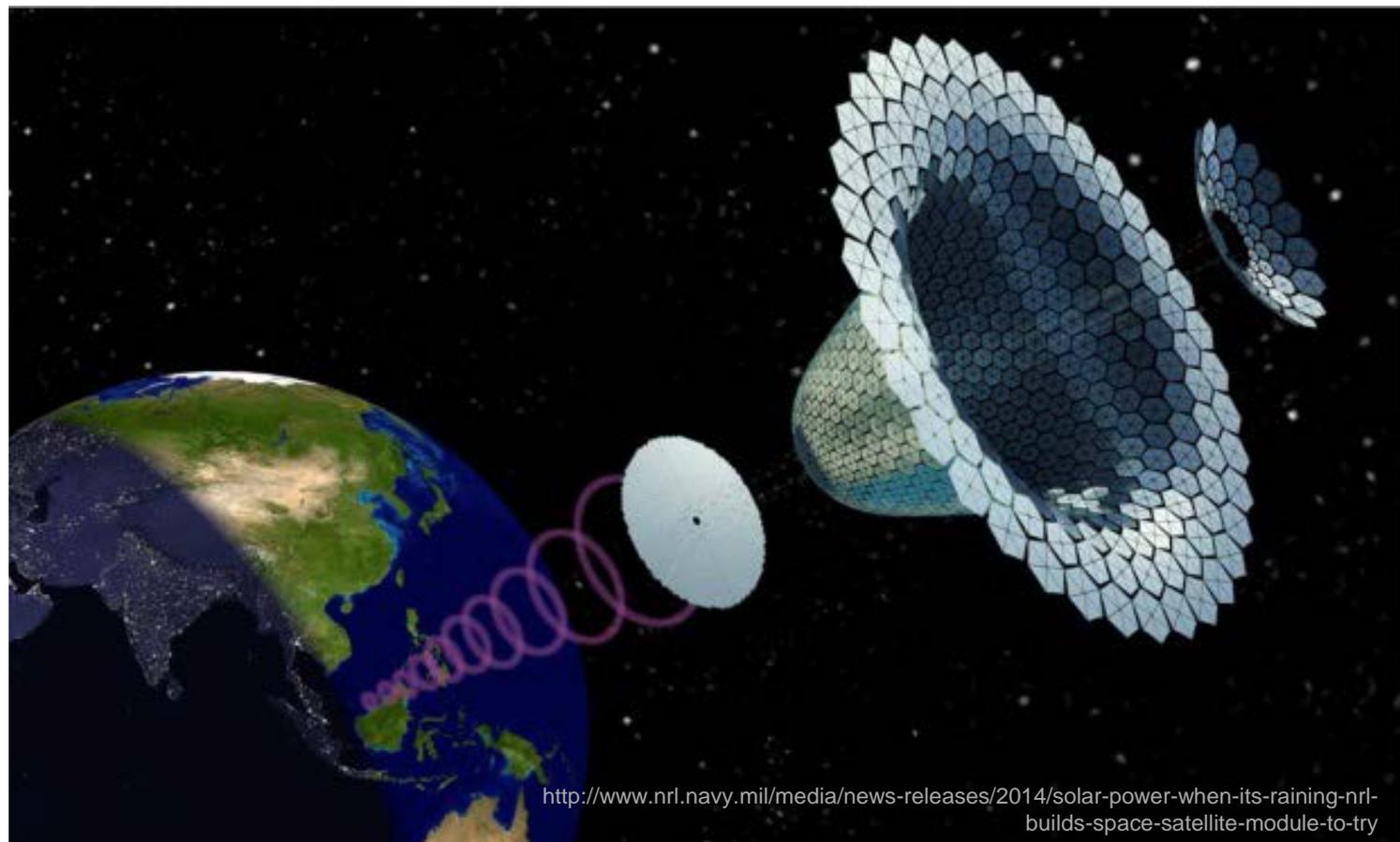
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Smart Buildings and Cities - 2040



Space-Based Solar Power



Reflectors concentrate sunlight onto solar arrays in geosynchronous orbit.
Satellites beam power to receiver on earth.
(Image: John C. Mankins, NASA)