Evaluation of the Feasibility of Avian Vaporization from Concentrating Solar Power Towers

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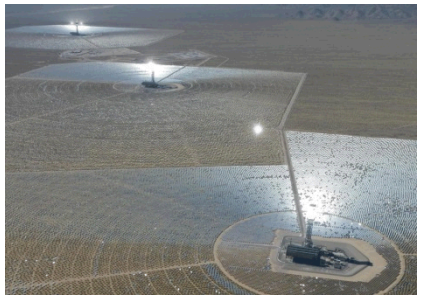

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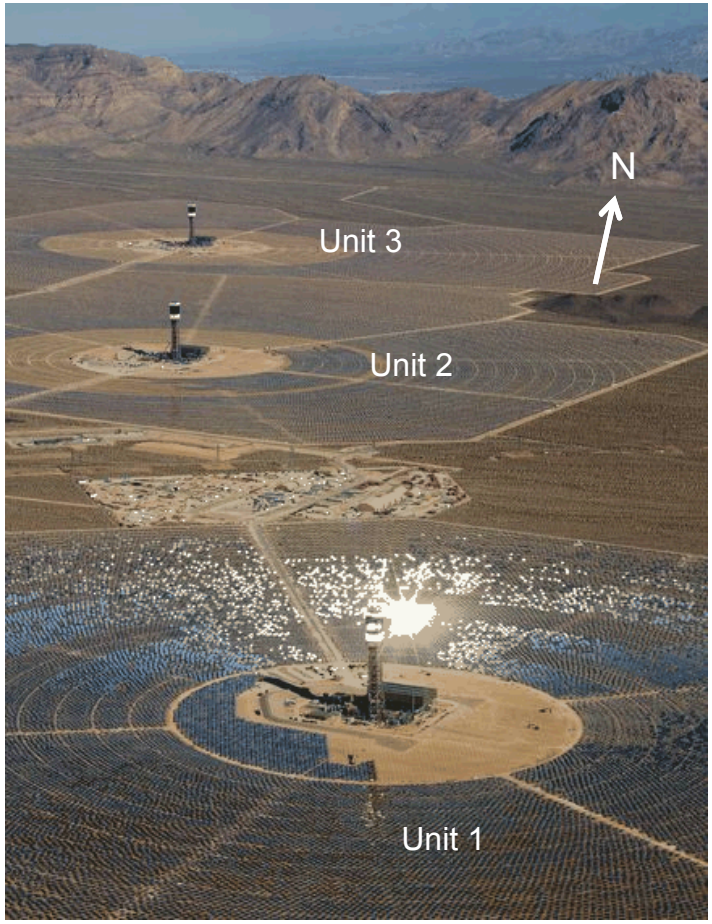
Ivanpah Solar Electric Generating System

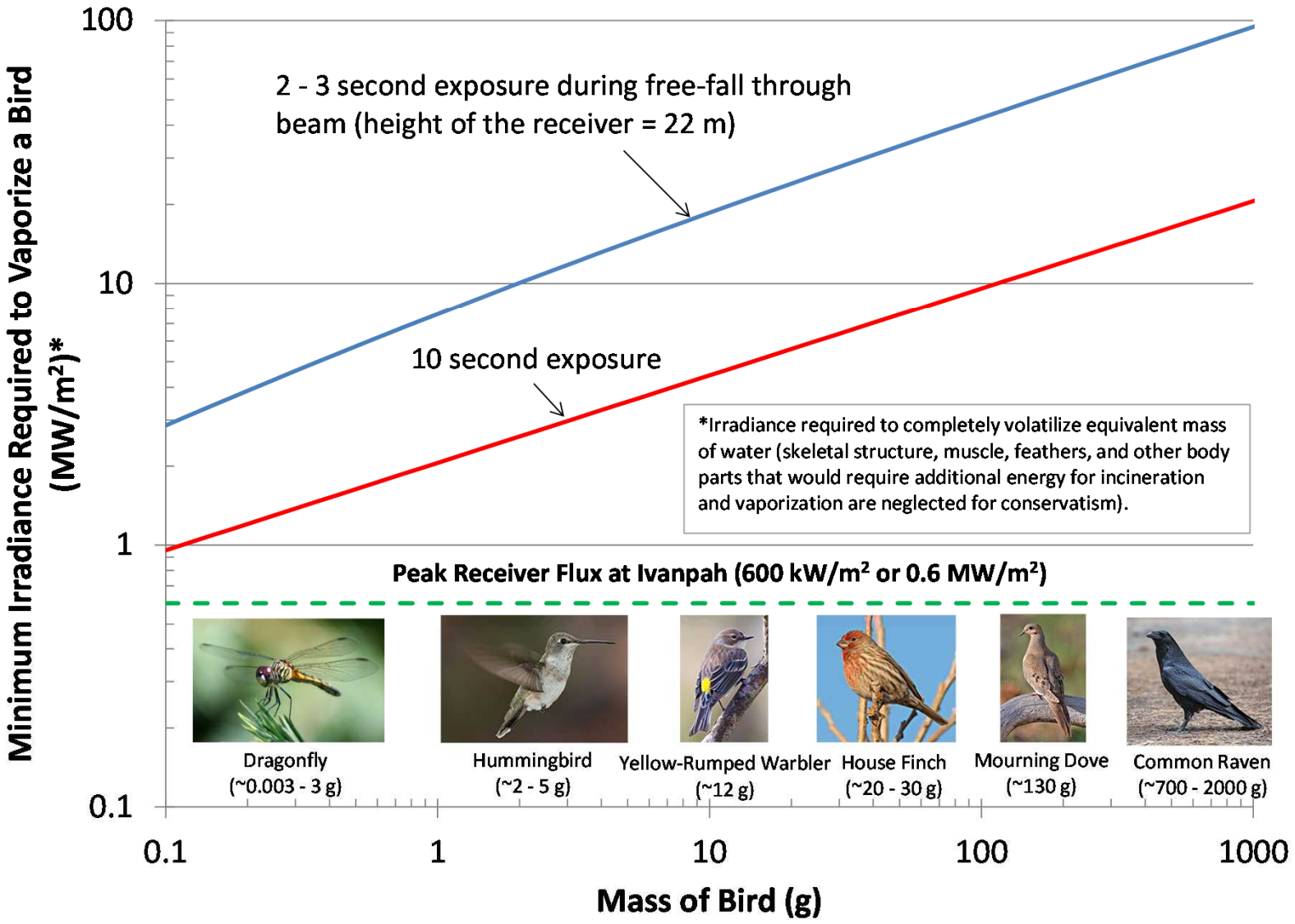
- Three power tower units
  (377 MW (net) / 392 MW (gross)
  - Unit 1: 126 MW
  - Unit 2: 133 MW
  - Unit 3: 133 MW
  - Each tower 140 m (459 ft) tall
- 173,500 heliostats
  - 2 mirrors/heliostat: 15.2 m^2
- Direct steam receiver (22 m tall x 17 m wide + ~16 m of white shielding)
- Dry-cooling
- 14.2 km^2 (3500 acres) on public desert land in southern California
- Owners: NRG Energy, Google, and Brightsource Energy



Vaporization Calculation

- Assume bird is composed entirely of water
- Determine energy required to volatilize equivalent mass of water (sensible heat plus latent heat)
  - Sensible (heating) energy to heat water from 40 C (average body temperature of bird) to 97 C (boiling point at elevation of Ivanpah)
  - Latent heat of vaporization to convert liquid water to vapor
- Convert energy (J) to irradiance (W/m^2) by dividing by exposure time (s) and cross-sectional area (m^2)
  - Two exposure times calculated
    - Free-fall through beam equivalent to height of receiver (22 m); ~2 – 3 sec
    - Fixed 10 sec exposure time
- Compare minimum irradiance required to volatilize a bird with prescribed mass to the peak available irradiance at Ivanpah

Irradiance Required to Vaporize a Bird



Conclusions

- Complete vaporization of birds with concentrated solar flux less than 1 MW/m^2 is highly improbable
- For most common birds between 10 – 1000 g, the irradiance would need to be 4 – 20 MW/m^2 with an exposure time of 10 sec to volatilize equivalent mass of water
  - Peak irradiance (solar flux) at Ivanpah is only ~0.6 W/m^2
  - Additional energy would be required to incinerate and vaporize bones, muscle, feather, and other body parts, which were neglected in this analysis

Appendices

- Free-fall and time of irradiance calculation
- Vaporization calculation
- References

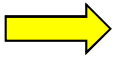
Free-Fall Calculation

- Free-fall time over distance, H, is as follows:

$$t = \frac{v_\infty}{g}\cosh^{-1}\left(\exp\left(\frac{Hg}{v_\infty^2}\right)\right)$$

where $v_\infty = \text{terminal velocity} = 1.286 m^{1/6} \rho_w^{1/3} \left(\frac{g}{\rho_a C_D}\right)^{1/2}$ assuming spherical body

g = gravitational accleration (9.81 m/s^2)
H = free-fall distance through beam = receiver height = 22 m
m = mass (kg)
ρ_a = density of ambient air = 1.2 kg/m^3
ρ_w = density of water = 992 kg/m^3 at 40 C
C_D = drag coefficient (~1 for passerine birds)*



Free-fall time through beam is ~2 – 3 sec, depending on mass

*Sum of three drag components: lift, profile, and parasite (Hedenstrom and Liechti, 2001)

Vaporization calculation

- Sensible (heating) energy:

$$E_{sensible} = mc_p \left(T_{boil} - T_{body} \right)$$

where

$E_{sensible}$ = sensible energy to bring water to boiling point (J)
m = mass (kg)
c_p = specific heat of water = 4200 J/kg-K (for T between 270 – 390 K)
T_{boil} = boiling point of water (= 97 C for atmospheric pressure at Ivanpah)
T_{body} = average body temperature of bird (= 40 C; Prinzinger et al., 1991)

Vaporization calculation

- Latent heating:

$$E_{latent} = mh_{fg}$$

where

E_{latent} = latent energy to volatilize liquid water (J)
m = mass (kg)
h_{fg} = latent heat of vaporization (=2.27e6 J/kg at 97 C)

Vaporization calculation

- Minimum irradiance required for vaporization

$$Q = \frac{E_{sensible} + E_{latent}}{At}$$

where

$$A = \frac{\pi^{1/3}}{4}\left(\frac{6m}{\rho_w}\right)^{2/3}$$

Q = irradiance (W/m^2)

$E_{sensible}$ = sensible energy to bring water to boiling point (J)

E_{latent} = latent energy to volatilize liquid water (J)

A = cross-sectional area of bird (m^2); assumed to be spherical in shape*

ρ_w = density of water = 992 kg/m^3 at 40 C

t = time of exposure (sec)

*Cross-sectional area of sphere is conservatively larger than estimates from Pennycuick (1989) for body frontal area, S_b: $S_b=0.00813m^{0.666}$

References

- Coles, B.H., 2007, *Essentials of avian medicine and surgery*, 3rd ed., Blackwell Pub., Oxford, UK ; Ames, Iowa, viii, 397 p.
- Hedenstrom, A. and F. Liechti, 2001, Field estimates of body drag coefficient on the basis of dives in passerine birds, *Journal of Experimental Biology*, **204**(6), p. 1167-1175.
- Pennycuick, C.J., 1989, *Bird flight performance : a practical calculation manual*, Oxford University Press, Oxford, England ; New York, x, 153 p.
- Prinzinger, R., A. Pressmar, and E. Schleucher, 1991, Body-Temperature in Birds, *Comparative Biochemistry and Physiology a-Physiology*, **99**(4), p. 499-506.