We conclude that the use of natural gas as a preferred fuel, particularly as a replacement for coal, could reduce climate forcing during the transition to cleaner-energy technologies. Cutting methane emissions is cost effective and will be beneficial both directly and indirectly by reducing tropospheric ozone[11], even as atmospheric carbon dioxide continues to increase at an accelerating pace.

J. Lelieveld*, S. Lechtenböhmer†, S. S. Assonov*, C. A. M. Brenninkmeijer*, C. Dienst†, M. Fischedick†, T. Hanke†

**Max Planck Institute for Chemistry, 55128 Mainz, Germany*

e-mail: lelieveld@mpch-mainz.mpg.de

†Wuppertal Institute for Climate, Environment and Energy, 42103 Wuppertal, Germany

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Planetary science

Constant illumination at the lunar north pole

Images returned by the spacecraft Clementine have been used to produce a quantitative illumination map of the north pole of the Moon, revealing the percentage of time that points on the surface are illuminated during the lunar day. We have used this map to identify areas that are constantly illuminated during a lunar day in summer and which may therefore be in permanent sunlight. All are located on the northern rim of Peary crater, close to the north pole. Permanently sunlit areas represent prime locations for lunar outpost sites as they have abundant solar energy, are relatively benign thermally (when compared with equatorial regions), and are close to permanently shadowed regions that may contain water ice.

Because the Moon's spin axis is nearly perpendicular (about 1.5°) to the ecliptic plane, astronomers have long considered that areas of illumination extremes may exist near the lunar poles[1]. Topographic lows, such as the floors of impact craters, can be permanently in shadow[2], whereas high areas could in theory be in constant sunlight. Permanently shadowed regions are extremely cold[3] and may contain deposits of water ice[4,5].

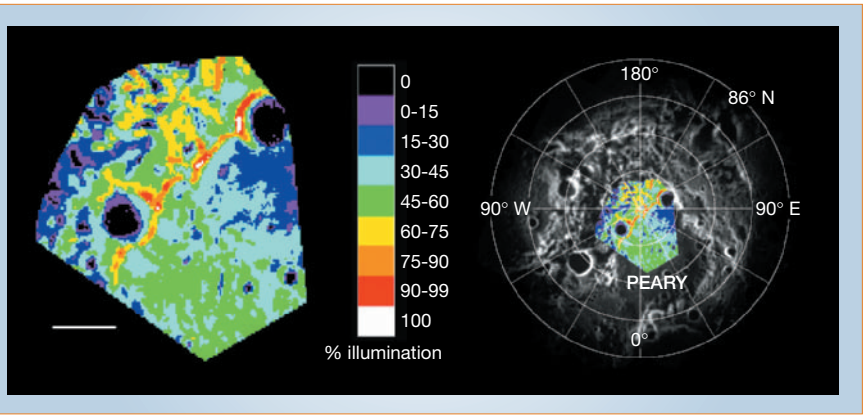

Figure 1 A quantitative illumination map of the Moon's north pole. The colour scale indicates the percentage of time that a point on the surface is illuminated during a lunar day in summer. Left, several areas on the rim of Peary crater (78 km in diameter) can be identified (white) that were continuously illuminated. The spatial extent of the map is within about 1–1.5° of the pole. Scale bar, 15 km. Right, colour illumination map superimposed on a greyscale composite Clementine mosaic, for spatial reference.

Conversely, the temperature in a permanently lit zone is relatively mild and constant because of the grazing insolation. The temperature at the lunar equator fluctuates from −180 °C to 100 °C, but the surface temperature for a constantly sunlit polar region has been estimated from modelling[6] to be roughly −50 ± 10 °C. A region with this relatively benign temperature range represents an attractive site for building hardware designed for long-term use.

The lunar north pole is in a highland region, in between three large impact craters[7] — Peary (88.6° N, 33.0° E; diameter, 73 km), Hermite (86.0° N, 89.9° W; diameter, 104 km) and Rozhdestvensky (85.2° N, 155.4° W; diameter, 177 km). Because the pole lies just outside the crater rims, it is likely to be at a relatively high elevation, increasing the likelihood that some areas could be permanently illuminated. By contrast, the lunar south pole is just inside the rim of the South Pole–Aitken impact basin (2,500-km diameter), and there is no area at this pole that is constantly illuminated during the southern winter, as measured at the scale of the Clementine UVVIS data (500 m per pixel)[8].

The Clementine spacecraft orbited the Moon in an elliptical orbit with a 5-hour period for 71 days in 1994, arriving in the northern hemisphere just after mid-summer (that is, when the spin axis was pointing towards the Sun)[9]. We have identified 53 images taken by the craft's UVVIS camera that cover the north pole with a spatial resolution of roughly 500 m per pixel. Each image encompasses an area of about 190 × 140 km. The images show which areas are illuminated as a function of solar azimuth during a lunar day in summer.

Our quantitative illumination map for the north polar region shows the percentage of time that a point on the surface is illuminated during a lunar summer day (Fig. 1). There are several regions, all on the rim of Peary crater, that are illuminated for the entire day (Fig. 1, white areas). With the information available, it is not possible to state definitively that these areas are permanently sunlit because the data correspond to a summer rather than a winter day. But we can be certain that they are the most illuminated regions around the north pole and that they are also the areas on the Moon most likely to be permanently sunlit, given that there are no constantly illuminated areas in the south polar region[8].

Our quantitative illumination map also identifies permanently shadowed areas. These are associated with small impact craters (3 km or less in diameter) on the floor of Peary crater, with two larger craters (14 and 17 km in diameter) on the rim of Peary, and with the area just outside Peary's rim, in the highland region (Fig. 1).

D. Ben J. Bussey*, Kirsten E. Fristad†, Paul M. Schenk‡, Mark S. Robinson§, Paul D. Spudis*

**Planetary Exploration Group, Space Department, The Johns Hopkins Applied Physics Laboratory, Laurel, Maryland 20902, USA*

e-mail: ben.bussey@jhuapl.edu

†Macalester College, Saint Paul, Minnesota 55105, USA

‡Lunar and Planetary Institute, Houston, Texas 77058, USA

§Center for Planetary Sciences, Northwestern University, Evanston, Illinois 60208, USA

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