The first mark was awarded for identifying one relevant green chemistry principle (GCP).

The second mark was awarded for using evidence to support/explain how the two methods relate to this GCP.

The third mark was awarded for identifying a second relevant GCP.

The fourth mark was awarded for using evidence to support/explain how the two methods relate to this GCP.

The fifth mark was awarded for providing a relevant ethical factor relating to global steel production.

The sixth mark was awarded for a concluding statement that related to the evidence the student provided.

Examples that could have been used for green chemistry principles included:

Prevention of waste

Data to use

comparing the relative amounts of CO_2 produced, OR

comparing both CO_2 and O_2 as waste/by-product with respect to their environmental impact.

The blast furnace process has a by-product of little industrial use (CO_2), so that becomes waste. MOE has no direct CO_2 emissions.

The MOE process has a by-product (O_2), but it is less harmful and has some industrial use, so it is not as harmful a 'waste' by-product as CO_2.

Design for energy efficiency

Data to use

comparing temperature requirements of the two processes, OR

comparing electrical energy requirements of the two processes.

The blast furnace needs more heat energy (2200 compared to 1600). This is more likely done through the burning of fossil fuels.

The MOE process needs more electrical energy than the blast furnace process. It could be argued that the former is not as energy efficient if done by using fossil fuels to produce the electricity. However, it could also be more energy efficient if both the heating stage and the electrolysis stage are done using electricity from renewable energy sources.

Note: Therefore, students could use data to justify either the blast furnace process OR the MOE process for this GCP.

Atom economy

Data to use

atom economy of two reactions, with Fe as the desired product.

Fe from BF process – 62.8%

Fe from MOE process – 69.9%

If the worded explanation is reasonable, students would not have to provide detailed mathematical proofs. For example, the blast furnace process has *more* mass of reactants (C, coke) and an undesired by-product with *more* mass (CO_2 compared to O_2), so logically the atom economy of the MOE process should be better.

Examples that could have been used for ethical factors included:

Any discussion connecting the argument that the MOE process would only be green and sustainable if electricity from renewable sources is used, and that *access* to this will vary significantly across countries/globally.

For example:

Renewable energy technology is not set up / accessible in all regions – some steel producers might want to change to the MOE process but cannot do so.

Renewable energy is needed for a lot of things, so an ethical question arises about whether the steel industry should receive priority access over other people/communities/industries.

Steel is produced on a massive scale and provides many jobs; a transition to the MOE process would require large numbers of workers to retrain, and some may lose jobs.

The MOE process is relatively untested and will take many years to scale up. Meanwhile, society will continue to rely on steel production.

Steel, as a polluting industry, is predominantly produced today in low- to middle-income countries or disadvantaged areas of industrial countries. There is potential for these areas to benefit from a process that uses renewable energy, including health benefits.

Platinum and iridium are already difficult-to-source (endangered) elements; a global switch to the MOE process would significantly increase demand and extraction of these metals, with hard-to-predict environmental and social consequences.