Technical Annex: Green Iron Definition and Reduction Pathway (CRT-Aligned)

1. Purpose of this Annex

This annex clarifies the technical definition of *green iron* and the acceptable iron-ore reduction pathways, with emphasis on system-level emissions outcomes rather than exclusive reliance on a single reducing agent. The intent is to ensure technology-neutral, scientifically accurate assessment aligned with zero-emission objectives.

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2. Definition of Green Iron (System-Correct)

Green iron is defined as metallic iron produced in an industrial facility that achieves **zero net greenhouse gas emissions at the defined plant boundary**, including energy supply, reduction reactions, and by-product handling.

Under this definition, the **choice of reducing agent (hydrogen, carbon monoxide, or combinations thereof)** is secondary to the requirement that **no fossil-derived carbon is emitted to the atmosphere**.

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3. Iron Ore Reduction Chemistry (Industrial Reality)

Iron ore reduction is fundamentally a redox process and can proceed via multiple well-established reactions:

- **Hydrogen reduction**

  $Fe_2O_3 + 3H_2 \rightarrow 2Fe + 3H_2O$

- **Carbon monoxide reduction**

  $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$

- **Combined (mixed-gas) reduction**

  $Fe_2O_3 + (H_2 + CO) \rightarrow 2Fe + (H_2O + CO_2)$

In commercial Direct Reduced Iron (DRI) furnaces, **hydrogen and carbon monoxide routinely coexist**, and metallisation is achieved by controlling gas composition, temperature, and residence time. Mixed H_2/CO reduction is therefore **technically proven and industrially scalable**.

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4. Emissions Are a System Outcome, Not a Molecule Choice

The environmental impact of ironmaking is determined not by whether hydrogen or carbon monoxide is used, but by **whether carbon exits the system as CO_2**.

Carbon-based reduction pathways are **not inherently high-emission**. Emissions arise only when carbon is used in an **open loop** (i.e. fossil carbon oxidised and released).

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5. CRT-Aligned Closed-Loop Carbon Reduction

Under **Carbon Recycling Technology (CRT)**, carbon monoxide used as a reducing agent operates within a **closed carbon loop**:

1. CO participates in iron ore reduction, forming CO_2
2. CO_2 is captured within the plant system
3. Captured CO_2 is converted, using renewable hydrogen, back into CO and/or methane
4. Recycled CO is returned to the reduction process

In this configuration:

- Carbon atoms circulate within the system
- Renewable hydrogen supplies the net energy input
- **No net CO_2 is released beyond the plant boundary**

This enables **zero-emission iron production**, even when carbon-containing reductants are used.

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6. Advantages of Combined H_2 + CO Reduction

A mixed hydrogen/carbon monoxide reduction strategy offers several system-level advantages while remaining fully compliant with green iron objectives:

- Reduced peak renewable electricity demand
- Lower electrolyser oversizing requirements
- Improved furnace thermal stability
- Compatibility with existing DRI platforms and assets

- Enhanced scalability and cost effectiveness

These benefits directly support industrial deployment and value-for-money outcomes sought by public funding programs.

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7. Alignment with Industrial Platforms

This definition and pathway are fully compatible with established DRI technologies, including platforms such as **Midrex Technologies, Inc.**, where reduction chemistry is decoupled from upstream energy and carbon-management systems.

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8. Concluding Statement

Green iron should be assessed based on verified zero-emission performance at the plant boundary, not on exclusive reliance on hydrogen as a reducing agent.

A combined H_2/CO reduction pathway, when integrated with closed-loop carbon recycling, represents a technically sound, industrially scalable, and emissions-compliant route to green iron production.