
Reaction Terminology and the Challenges for Energy and Environmental Policy

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This technical brief aims to provide clarity around the types of chemical reactions used in power generation and to help explain how the reaction used in Mainspring's new category of power generation – the linear generator – is different from the reactions used in other commercially available technologies.

To begin, it's important to note that neither the power generation industry nor the energy policy and regulatory spheres today operate on precise or agreed-upon definitions with respect to reaction terminology. This notable lack of definitions leaves a gap for misuse and misinterpretation of terminology across the industry as new technologies come to market and new policies and regulations emerge.

While the best energy policies are designed to keep pace with innovation, imprecise use of terms like "combustion" or "non-combustion" can have unforeseen consequences, such as placing focus on considerations irrelevant to the intent of a given policy or regulation or creating unnecessary distortions in the market.

Mainspring hopes this paper will meaningfully contribute to the conversation around energy and environmental policy as the industry moves urgently towards decarbonization. We believe the best way to encourage and keep pace with innovation is by creating policies that establish clear goals rather than prescribed pathways. In this case, it would be more effective to set clear emissions output requirements for power generation technologies rather than to pick specific technologies or use undefined or ambiguous reaction terminology. This is the best way to meet the goal of a highly resilient, affordable, net-zero carbon electric grid.

What is a reaction?

At the heart of any type of fuel-based power generation is a chemical reaction. A chemical reaction is needed to ultimately convert the energy in a fuel into useful, or usable, energy -- whether electrical energy or mechanical energy.

At a fundamental level, the chemical reactions involved in power generation combine a fuel and oxygen (O₂), typically from air, in a way that produces reaction products at a lower energy state.



The difference in energy between the fuel and the reaction products is what is available to produce useful energy. Regardless of the type of reaction, the process and primary reaction products are the same for a given fuel. For hydrocarbon fuels (C_xH_y), the primary reaction products are carbon dioxide (CO₂) and water (H₂O), and for hydrogen (H₂), the primary reaction product is water. When air is used for the reaction, the nitrogen (N₂) in the air remains unchanged in the reaction products.

Reactions in Practice: Method Matters

The way in which reactions occur in practical applications matters because of the types of reaction products produced.

One of the more highly regulated reaction products is that of nitrogen oxides (NO_x , pronounced “nox”) because it is a precursor to smog. NO_x is formed when a reaction between fuel and air takes place at high enough temperatures (more than 1500 C) to break apart nitrogen (N_2) into atomic nitrogen (N), which then combines with oxygen (O_2) to form nitrogen oxide (NO) and nitrogen dioxide (NO_2) — collectively referred to as nitrogen oxides (NO_x). In combustion-based power generation (i.e., engines and turbines), NO_x emissions are typically reduced and managed with catalyst after-treatment equipment.

Types of Common Reactions

Combustion Reactions

The term combustion is well known, since most people are familiar with the internal combustion engine in their cars. Internal combustion engines convert the energy in fuel into mechanical work (i.e., the spinning of a crankshaft). In cars, this mechanical energy is used to turn a drivetrain, the car’s transmission and wheels, and in power generation it is used to spin an electric generator.

There are two types of reactions used in combustion engines: spark ignition (SI), typically used in gasoline and natural gas engines, and direct injection (DI), typically used in diesel engines. In SI reactions, a spark plug is used to create a flame that burns a fuel and air mixture in the engine cylinder. In DI reactions, liquid fuel is injected directly into hot air in the engine cylinder, which creates a flame that evaporates and burns the fuel in air.

Both SI and DI reactions are referred to as combustion or combustion reactions because they use a flame to burn fuel in air, which results in high temperatures (more than 1500 C) that produce high NO_x emissions. In SI engines, NO_x emissions can be reduced through the use of 3-way catalysts, typical in gasoline engines and some gas engines, or selective catalytic reduction systems for some gas engines, which results in toxic ammonia emissions. Selective catalytic reduction systems are also used to reduce NO_x emissions from DI engines, with varying degrees of success.

Even with these after-treatment solutions, NO_x emissions from combustion reactions are high relative to more advanced technologies. Additionally, these after-treatment technologies require high temperatures, and therefore require a start-up period during which emissions are orders of magnitude higher than during steady state operation.¹

Electrochemical Reactions

Electrochemical reactions are the types of reactions used in fuel cells. They use a combination of catalysts and electricity production (via an electrical potential) to drive a chemical reaction on or near the surface of the catalyst. The electrochemical oxidation reactions that occur in fuel cells are exothermic, meaning they generate heat. Commercial fuel cells operate at a low enough temperature (typically less than 1000 C) that their reaction produces near-zero NO_x emissions.

In contrast to engines, which produce mechanical work that can then be converted into electrical energy through the use of a generator, fuel cells only operate with electricity production. This in

¹ <https://agoraenvironmental.com/papers/SUSD%20Chicago%20Paper.pdf>

combination with their low NO_x emissions is why fuel cells are regulated differently than engines and turbines.

Mainspring Linear Generator's Low-Temperature Reaction

The unique design and advanced controls used in Mainspring linear generators enable both the direct conversion of linear motion into electricity and use of a low-temperature reaction that produces near-zero NO_x emissions.

In Mainspring's linear generator, electrically-controlled linear motion of oscillators compress a fuel and air mixture until the mixture reacts uniformly and near instantaneously without a flame or burning. Since there is no flame or burning (i.e., no combustion), the reaction occurs at low temperatures (less than 1500 C) and, as a result, produces near-zero NO_x emissions. The energy from the low-temperature reaction drives linear motion of the oscillators, which is directly converted into electricity, and the electrically-controlled linear motion of the oscillators drives the reaction.

Much like a fuel cell, Mainspring's linear generator only operates while producing electricity. This is in contrast to an engine, which can only operate by producing mechanical energy.

Chemical Reaction Terminology and its Impact on Policy

Until the arrival of Mainspring's linear generator, there have been two categories of commercially available power generation technologies — those that use burning or combustion reactions and those that use electrochemical reactions. The differences in the reaction products between these two types of reactions has created a false dichotomy in public perception with "combustion" being a proxy for "dirty and unhealthy" and "non-combustion" being a proxy for "clean". The truth is that the terminology or classification of "combustion" and "non-combustion" is technically ambiguous. Combustion can be defined as anything from "*the act or instance of burning*" to "*a rapid oxidation that produces heat,*" with the latter including any and every type of generating technology and reaction pathway, including fuel cells.^{2,3}

Fortunately, there is a better path forward. Rather than trying to agree on definitions and terminology for reaction pathways used in specific technologies, we suggest focusing on the right outcome — low emissions. By focusing on emissions rather than reaction pathways, we avoid unproductive debates over technical complexity. We encourage policy makers and regulators to establish clear emissions standards that allow any technology or reaction pathway, today or in the future, that meets those standards to help accelerate our transition to a net-zero carbon grid.

² <https://www.britannica.com/science/combustion/History-of-the-study-of-combustion>

³ <https://www.merriam-webster.com/dictionary/combustion>