Executive summary

This report was prepared at the request of the Dutch government and funded by the European Commission's (EC) Directorate-General for Structural Reform Support (DG REFORM). The findings and recommendations in the report are tailored to the Dutch context but may be relevant for other countries, taking into account contextual specificities. It aims to support the transition towards wide-spread use of low-emission hydrogen, by developing a set of recommendations on its regulation and governance. To do so, the report analyses six distinct scenarios that cover different parts of the hydrogen lifecycle from production to usage. These scenarios have been selected at the request of the Dutch Ministry of Economic Affairs and Climate Policy.

Sound, risk-proportionate regulatory policy and governance are crucial to drive the energy transition and enable the development of low-carbon energy solutions like low-emission hydrogen. Hydrogen, if produced from low-emission sources, can decarbonate "hard-to-abate" sectors still relying on fossil fuels, including in transport, turn low-carbon electricity into a fuel that can be transported through pipelines and allows for longer-term energy storage. Hydrogen can thus allow for a net reduction in societal risks, if managed responsibly. However, while its potential is widely acknowledged, rollout is not yet meeting many countries' strong ambitions, and perceptions and regulatory frameworks may be part of the issue. Regulation is a key element to ensure the hydrogen strategies of governments can materialise in practice, by facilitating the rollout of hydrogen technologies and ensuring their safety. A smooth deployment will require an enabling regulatory framework that is innovation-friendly, consistent, and agile, based on up-to-date evidence on actual risks.

The main findings and recommendations from the report are discussed below.

Advances in knowledge and technologies allow for a better management of hydrogen risks

Technological advances and increased scientific knowledge have decreased the "unknown risks" surrounding hydrogen use, reducing the need for additional caution compared to hydrocarbon fuel technologies. The behaviour and risks of hydrogen are currently better known and, if managed properly, hydrogen is overall not riskier than hydrocarbon fuels for many applications considered in this report, even when considering only safety risk in the narrowest sense.

Major hydrogen-linked accidents can, beyond their direct human harm, hinder further development of hydrogen through a loss of trust. Ensuring *effective* regulation is key – which requires adequate technical requirements, based on the latest research and technological advances, and supported through well-targeted, risk-based enforcement. Accidents and pilots can feed into improvements in technical designs and regulations to reduce future risks. Combining this with safe-by-design approaches, along with new knowledge as it arises, can help target the underlying causes of accidents and reduce risks.

Holistic risk assessments can ensure regulation effectively balances the multiple risks at stake

No technology is entirely risk-free. Safety is relative, and the risks of hydrogen technologies can be compared with other energy technologies. In some cases, behavioural biases such as the "risk regulation reflex", a "rush to judgement" and "path dependency" may come into play; addressing them requires clear information, communication, and science-based decision making.

Holistic risk assessments can ensure that the regulation of hydrogen also consider hydrogen's role in decarbonising and mitigating climate change risks. Safety risks and measures should be risk-proportionate and weighed against climate change-related risks of "stalled innovation", among others. Risk mitigation strategies should not discriminate against new technologies and demand higher levels of safety than is required of high-carbon, existing technologies. This can achieve a well-managed balance of safety, health, environmental, social, political, and economic risks.

Additional caution should be applied where necessary and when risks are still largely unknown

Safety knowledge varies across hydrogen technologies, and thus they can be regulated differently. When scientific knowledge is more limited and risks are less known, additional pilots can improve scientific knowledge, while using more adaptive, iterative approaches to improve regulation as technology advances.

Risk-focused regulatory delivery can reduce unnecessary regulatory burdens

Focusing on outcomes rather than prescribing detailed procedures can support efficient licensing, inspection and enforcement practices. This could involve limiting permitting requirements to the minimum necessary and making procedures more proportionate and streamlined. It could also involve ensuring zoning policies allow for the use of hydrogen in a risk-proportional way.

Effective communication and guidance can support public trust and an enabling investment climate

While there are real risks associated with hydrogen, there are often large gaps between risk *perceptions* and science-based risk assessments. Clear engagement and messaging on risks and safety measures can promote correct perceptions and build public support and trust for a transition to hydrogen. Clear guidance for zoning officials, permitting and inspection bodies, and one-stop shops can be used to facilitate hydrogen roll-out.

Role clarity, effective co-ordination and sufficient resources can empower public institutions to keep pace with changes

Legislation should establish clear mandate, powers and objectives for all authorities involved with hydrogen. A formalised co-ordination platform across levels of government should further strengthen regulatory co-operation and consistency. Furthermore, resourcing frameworks should be sufficiently agile to allow bodies to act on new mandates and recruit or develop necessary skills.