

CONTENTS

About the author	1
Executive Summary	4
1. Introduction: The new hydrogen economy	7
1.1 Why hydrogen?.....	7
1.2 Growing policy attention and support for hydrogen as a clean energy carrier.....	8
1.3 Current hydrogen market.....	15
1.4 New roles as an enabler of deep decarbonisation.....	16
1.5 Future potential demand	22
2. Options for producing clean hydrogen at scale.....	25
2.1 Natural gas reforming with CCS	25
Hydrogen and CCS value chains	25
Global hydrogen-CCS projects	27
Renewed interest in CCS, driven by Europe and the US.....	27
CCS indispensable for producing clean hydrogen at scale	30
2.2 Water electrolysis using renewables.....	30
Three main types of electrolyzers	30
Exponential development.....	33
Mass production is needed to achieve costs reductions.....	39
2.3 Pyrolysis	39
2.4 Cost comparisons and future evolution	40
Reforming with CCS.....	40
Water electrolysis.....	41
Comparison of future costs	43
2.5 Scale of clean hydrogen production	43
2.6 Conclusion: Blue vs. green hydrogen? Both routes will support the new hydrogen economy.....	45
3. International clean hydrogen supply chains	47
3.1 Clean hydrogen as an internationally traded commodity	47
3.2 International trade: Japanese demonstration projects	52
LH ₂	52
MCH	55
NH ₃	57
3.3 Clean hydrogen trade in Europe	59
Norway's HYPER project.....	59
HY3 project.....	60
3.4 Technical and cost issues.....	61
Environmental footprint.....	61
System efficiency	61
Delivered cost of clean hydrogen	62
3.5 Conclusion: Establishing cost-efficient international supply chains	64

Annex 1: CCS projects involving hydrogen	66
Annex 2: Focus on large scale Power-to-X projects	70
Annex 3: Power-to-X projects in the world	73
Main Abbreviations	75
List of Figures, Tables and Boxes	77