

REFINERY TRANSFORMATION: TECHNOLOGY-DRIVEN STRATEGIES FOR SUSTAINABLE PROFITABILITY IN A CHANGING BUSINESS ENVIRONMENT

TABLE OF CONTENTS

SECTION 1 INTRODUCTION

SECTION 2 EXECUTIVE SUMMARY

SECTION 3 ENVIRONMENTAL LEGISLATION AND CLIMATE SCRUTINY

3.1 WORLDWIDE

3.1.1 Net-zero Goals

3.1.1.1 Methane Emissions

3.1.2 Emissions Trading

3.1.3 Phasing Out Internal-combustion Engines and the Rise of NEVs

3.1.4 Aviation

3.1.5 Maritime Regulations and Trends

3.1.6 ESG Impact on Business Environment

3.1.6.1 Windfall Taxes

3.2 UNITED STATES

3.3 CANADA

3.4 LATIN AMERICA

3.5 WESTERN EUROPE

3.6 CENTRAL AND EASTERN EUROPE

3.7 MIDDLE EAST

3.8 AFRICA

3.9 ASIA-PACIFIC

SECTION 4 MARKET CHALLENGES AND OPPORTUNITIES: CRUDE OIL, FUELS, AND PETROCHEMICALS

4.1 WORLDWIDE

4.1.1 Global Crude Market

4.1.1.1 Global Crude Supply

4.1.1.2 Global Crude Demand and Competition from Alternative Fuels

4.1.1.3 Crude Price Trends and Impacts on Refinery Carbon Footprint

4.1.2 Global Refined Products Market

4.1.2.1 Global Refined Products Supply: Eastward Shift in Refining Capacity

4.1.2.2 Global Refined Products Demand

4.1.3 Global Petrochemicals Market

4.1.3.1 Global PC Supply

4.1.3.2 Global PC Demand

4.1.3.3 Refiners' and PC Producers' Roles in Meeting PC Demand amid the Energy Transition

4.1.3.4 Conclusion

4.2 UNITED STATES

4.3 CANADA

4.4 LATIN AMERICA

4.5 WESTERN EUROPE

4.6 CENTRAL AND EASTERN EUROPE

4.7 MIDDLE EAST

4.8 AFRICA

4.9 ASIA-PACIFIC

SECTION 5 RENEWABLE ENERGY BUSINESS OUTLOOK, COMMERCIAL TECHNOLOGIES, AND REFINERY IMPLEMENTATIONS

5.1 BUSINESS OUTLOOK

5.1.1 Transition Issues

5.1.1.1 Investment for the Energy Transition

5.1.1.2 Offshore Energy Hubs

5.1.1.3 Natural Gas as a Transition Fuel

5.1.2 Solar Energy

5.1.3 Wind Energy

5.1.4 Geothermal Energy

5.1.5 Nuclear Energy

5.1.6 Alternative Vehicles

5.1.6.1 Fuel Cells

5.1.6.2 Mineral Supplies

5.1.7 Hydrogen

5.1.8 On-road Biofuels and Renewable Fuels

5.1.8.2 Ethanol

5.1.8.3 E-fuels

5.1.9 Sustainable Aviation Fuel

5.1.10 Biofeed Options: Palm Oil

5.1.11 Alternative Marine Fuels

5.1.11.1 Liquefied Natural Gas

5.1.11.2 Hydrogen

5.1.11.3 Dual-fueled Vessels

5.1.12 RNG, Bio-LNG, and Biomethane

5.1.13 Carbon Capture (Utilization) and Sequestration

5.1.13.1 Capacity

5.1.13.2 Market Value

5.1.13.3 Carbon Transportation

5.1.13.4 CCUS in the Shipping Sector

5.1.14 Carbon Offsets

5.1.15 Recycled Feedstocks: Hydrotreated Vegetable Oil

5.1.16 Recycled and Bio-PCs, Bio-polymers, and Bio-plastics

5.1.16.1 Recycled and Bio-petrochemicals

5.1.16.2 Recycled Polymers and Plastics

5.1.16.3 Bio-polymers and Plastics

5.1.16.4 Strategies amid Competition with Recycled and Bio-PCs, Polymers, and Plastics

5.1.17 Electrification

5.2 REGIONAL OUTLOOK

5.2.1 United States

5.2.2 Canada

5.2.3 Latin America

5.2.4 Western Europe

5.2.5 Central and Eastern Europe

5.2.6 Middle East

5.2.7 Africa

5.2.8 Asia-Pacific

5.3 COMMERCIAL TECHNOLOGIES

5.3.1 Wind Turbines

5.3.1.1 Rotor

- 5.3.1.2 Drivetrain
- 5.3.1.3 Controls
- 5.3.1.4 Tower/Balance of System

5.3.2 Hydropower Plants

- 5.3.2.1 Storage
- 5.3.2.2 Pumped Storage
- 5.3.2.3 Run-of-river
- 5.3.2.4 Instream
- 5.3.2.5 Hybrid

5.3.3 Photovoltaic Cells

- 5.3.3.1 Crystalline Silicon
- 5.3.3.2 Thin-film
- 5.3.3.3 Concentrating Solar Power Systems

5.3.4 Biomass

5.3.5 Geothermal

5.4 REFINERY IMPLEMENTATION

5.4.1 Energy Requirements and CO₂ Emissions

5.4.2 Renewables Use in Refineries

- 5.4.2.1 Process Heating
- 5.4.2.2 Steam Production
- 5.4.2.3 Combined Heat and Power Plant Replacement
- 5.4.2.4 Hydrogen Generation
- 5.4.2.5 Cost Comparison of Renewable and Conventional Energies
- 5.4.2.6 Conclusion

5.4.3 Refinery Installations of Renewable Energy

- 5.4.3.1 North America
- 5.4.3.2 Europe
- 5.4.3.3 Asia-Pacific

SECTION 6 COMPETITION IN REFINERY TRANSFORMATION

6.1 WORLDWIDE OVERVIEW OF COMPANY TARGETS FOR GHG EMISSIONS

6.2 COMPANY TRANSFORMATION: BALANCING TRADITIONAL AND ALTERNATIVE ENERGY

- 6.2.1 United States
- 6.2.2 Canada
- 6.2.3 Latin America
- 6.2.4 Western Europe
- 6.2.5 Central and Eastern Europe
- 6.2.6 Middle East
- 6.2.7 Africa
- 6.2.8 Asia-Pacific

6.3 CONCLUSION

SECTION 7 TECHNOLOGY ADVANCES IN TRANSFORMATION TO SUSTAIN PROFITABILITY FOR THE LONG TERM

7.1 PROFITABILITY ENHANCEMENT THROUGH ENERGY SAVINGS AND PRODUCTIVITY IMPROVEMENTS: UNIT-BY-UNIT ASSESSMENTS

7.1.1 Energy Management

- 7.1.1.1 Unit Assessments
- 7.1.1.2 Heat Exchanger Design Innovations, Maintenance, and Operation
- 7.1.1.3 Fired-heater Improvements
- 7.1.1.4 Utility-system Monitoring, Modeling, and Optimization
- 7.1.1.5 Industrial Internet of Things in Energy Management and Self-service Analytics
- 7.1.1.6 Plant Practices and Operational Experiences
- 7.1.1.7 Future Technology Trends

7.1.1.8 Conclusion

7.1.2 Productivity Increases

7.1.2.1 Unit Assessments

7.1.2.1.1 Crude Distillation: Atmospheric and Vacuum

7.1.2.1.1.1 Commercial Processes

7.1.2.1.1.2 Operational Flexibility to Handle Opportunity Crudes

7.1.2.1.1.3 Crude-feed Preheating

7.1.2.1.1.4 Operational Improvements and Optimization

7.1.2.1.1.5 Hardware Equipment

7.1.2.1.1.6 Heat-system Designs

7.1.2.1.1.7 Mitigation of Fouling, Corrosion, and Coke Formation

7.1.2.1.1.8 CDU Innovations to Aid Decarbonization

7.1.2.1.1.9 Internet of Things, Refinery Digitalization, Machine Learning and Artificial Intelligence

7.1.2.1.1.10 Conclusion

7.1.2.1.2 Coking

7.1.2.1.2.1 Commercial Processes

7.1.2.1.2.2 Coke-type Specific GHG Emission Mitigation

7.1.2.1.2.2.1 Delayed Coking

7.1.2.1.2.2.2 Fluid Coking

7.1.2.1.2.2.3 FLEXICOKING

7.1.2.1.2.2.4 Coke-calcining Units

7.1.2.1.2.3 Plant Practices and Operational Experiences

7.1.2.1.2.3.1 Energy Efficiency and Environmental Emissions

7.1.2.1.2.3.2 Process Modifications

7.1.2.1.2.3.3 Controlling Emissions

7.1.2.1.2.3.4 Maintenance Improvements

7.1.2.1.2.3.5 Carbon Capture (Utilization) and Sequestration

7.1.2.1.2.4 Conclusion

7.1.2.1.3 Fluid Catalytic Cracking

7.1.2.1.3.1 Commercial Processes

7.1.2.1.3.2 Commercial Catalysts

7.1.2.1.3.3 Major Sources of GHG Emissions and Mitigation Solutions

7.1.2.1.3.3.1 Combustion of Fuel

7.1.2.1.3.3.2 Flaring and Venting

7.1.2.1.3.3.3 Heat Loss

7.1.2.1.3.3.4 Coke Yield

7.1.2.1.3.3.5 Catalyst Regeneration

7.1.2.1.3.3.6 Energy Efficiency

7.1.2.1.3.3.7 Efficient and Coke-selective Catalysts

7.1.2.1.3.4 Technology Innovations in Decarbonization

7.1.2.1.3.4.1 Advanced Hardware Equipment

7.1.2.1.3.4.2 Internet of Things and Digitalization in FCC

7.1.2.1.3.4.3 Carbon Capture (Utilization), and Sequestration

7.1.2.1.3.5 Plant Practices and Operational Experiences

7.1.2.1.3.5.1 Unit Optimization

7.1.2.1.3.5.2 Steam-generation-boiler Performance

7.1.2.1.3.5.3 Heat Integration

7.1.2.1.3.5.4 Combined Heat and Power

7.1.2.1.3.5.5 Fuel-gas Leaks and Treatments Impacting GHG Emissions

7.1.2.1.3.5.6 Refinery Gas Flaring

7.1.2.1.3.5.7 Hydrocracking More VGO

7.1.2.1.3.5.8 Maintenance Practices

7.1.2.1.3.5.9 Carbon Capture

7.1.2.1.3.6 Conclusion

- 7.1.2.1.4 Hydrotreating
 - 7.1.2.1.4.1 Commercial Processes
 - 7.1.2.1.4.2 Commercial Catalysts
 - 7.1.2.1.4.3 Major Sources of GHG Emissions and Mitigation Solutions
 - 7.1.2.1.4.3.1 Hydrotreating of Specific Feed Streams
 - 7.1.2.1.4.3.2 Auxiliary Catalyst Technologies to Raise Productivity and to Cut Carbon Footprint
 - 7.1.2.1.4.3.3 Hydrogen Consumption
 - 7.1.2.1.4.3.4 Reactor Pressure Drop and Commercial Solutions
 - 7.1.2.1.4.4 Reactor Internals for Gas-liquid Distribution
 - 7.1.2.1.4.5 Improved Catalysts
 - 7.1.2.1.4.6 Technology Innovations in Decarbonization
 - 7.1.2.1.4.6.1 Biofeed Coprocessing
 - 7.1.2.1.4.6.2 Alternative Desulfurization Processes
 - 7.1.2.1.4.7 Plant Practices and Operational Experiences
 - 7.1.2.1.4.7.1 Unit-equipment Inefficiency and Improvements
 - 7.1.2.1.4.7.2 Steam-turbine Replacement
 - 7.1.2.1.4.7.3 Liquid Maldistribution
 - 7.1.2.1.4.7.4 Catalyst Deactivation
 - 7.1.2.1.4.7.5 Parameters Impacting Hydrogen Purity in Recycle Gas
 - 7.1.2.1.4.8 Conclusion
- 7.1.2.1.5 Hydrocracking
 - 7.1.2.1.5.1 Commercial Processes
 - 7.1.2.1.5.2 Commercial Catalysts
 - 7.1.2.1.5.3 Major Sources of GHG Emissions and Mitigation Solutions
 - 7.1.2.1.5.3.1 Energy-efficiency Improvements
 - 7.1.2.1.5.3.2 Unit Fouling
 - 7.1.2.1.5.3.3 Auxiliary Catalyst Technologies to Raise Productivity and Cut Carbon Footprint
 - 7.1.2.1.5.3.4 Hydrogen Consumption
 - 7.1.2.1.5.4 Commercial Hydrogen-saving Processes and Catalysts
 - 7.1.2.1.5.4.1 Processes and Hardware
 - 7.1.2.1.5.4.2 Catalysts and Additives
 - 7.1.2.1.5.5 Process Integration to Raise Productivity and to Minimize H₂ and Energy Demand
 - 7.1.2.1.5.6 Recovering Spent Hydroprocessing Catalysts and Metal Reclamation
 - 7.1.2.1.5.7 Technology Innovations in Decarbonization
 - 7.1.2.1.5.7.1 Advanced Process Control and Modeling
 - 7.1.2.1.5.7.2 Predictive Analytics
 - 7.1.2.1.5.7.3 Renewable-feeds Hydrocracking
 - 7.1.2.1.5.8 Plant Practices and Operational Experiences
 - 7.1.2.1.5.8.1 Energy-management System
 - 7.1.2.1.5.8.2 Steam-generation-boiler Performance
 - 7.1.2.1.5.8.3 Process-heater Performance
 - 7.1.2.1.5.8.4 Fuel-gas Leaks and Treatments Impacting GHG Emissions
 - 7.1.2.1.5.8.5 Refinery Gas Flaring
 - 7.1.2.1.5.8.6 Catalyst Selection to Reduce Pressure Drop and Energy Use
 - 7.1.2.1.5.8.7 Online Cleaning to Save Energy
 - 7.1.2.1.5.8.8 Simulation Modeling to Optimize Energy Efficiency
 - 7.1.2.1.5.8.9 Refinery Revamps to Produce Renewable Diesel
 - 7.1.2.1.5.8.10 Carbon Capture
 - 7.1.2.1.5.9 Conclusion
- 7.1.2.1.6 Catalytic Reforming
 - 7.1.2.1.6.1 Commercial Processes
 - 7.1.2.1.6.2 Commercial Catalysts
 - 7.1.2.1.6.3 Major Sources of GHG Emissions and Mitigation Solutions
 - 7.1.2.1.6.3.1 Reformer Heat Exchanger

- 7.1.2.1.6.3.2 Fired Heater Capacity and Efficiency
- 7.1.2.1.6.3.3 Process Control
- 7.1.2.1.6.4 Plant Practices and Operational Experiences
 - 7.1.2.1.6.4.1 Steam-generation-boiler Performance
 - 7.1.2.1.6.4.2 Process-heater Performance
 - 7.1.2.1.6.4.3 Combined Heat and Power
 - 7.1.2.1.6.4.4 Fuel-gas Leaks and Treatments Impacting GHG Emissions
 - 7.1.2.1.6.4.5 Refinery Gas Flaring
 - 7.1.2.1.6.4.6 Carbon Capture
- 7.1.2.1.6.5 Conclusion
- 7.1.2.1.7 Hydrogen Production via Grey, Blue, and Green Routes
 - 7.1.2.1.7.1 Commercial Conventional (Grey) Hydrogen Production Processes and Hardware
 - 7.1.2.1.7.2 Commercial Conventional (Grey) Hydrogen Production Catalysts
 - 7.1.2.1.7.3 Impacts of Decarbonization Drive on Hydrogen Production
 - 7.1.2.1.7.3.1 Hydrogen Production via Conventional, Grey Route
 - 7.1.2.1.7.3.2 H₂ Purification, Recovery, and Management
 - 7.1.2.1.7.3.3 Innovations in Hydrogen Production via Blue and Green Routes
 - 7.1.2.1.7.4 Plant Practices and Operational Experiences
 - 7.1.2.1.7.4.1 Meeting Rising Hydrogen Demand
 - 7.1.2.1.7.4.2 Hydrogen Management and Optimization
 - 7.1.2.1.7.4.3 Steam Reforming
 - 7.1.2.1.7.4.3.1 Feedstock Flexibility
 - 7.1.2.1.7.4.3.2 Processing Heavier Hydrocarbons in Steam Reforming
 - 7.1.2.1.7.4.3.3 Installing Prereforming Technology
 - 7.1.2.1.7.4.3.4 Autothermal Reforming as an Alternate to Steam Reforming
 - 7.1.2.1.7.4.3.5 Impact of Operational Parameters on Hydrogen Production Cost
 - 7.1.2.1.7.4.4 Hydrogen Recovery and Purification
 - 7.1.2.1.7.4.4.1 Technology Options
 - 7.1.2.1.7.4.4.2 Identifying Recoverable Hydrogen
 - 7.1.2.1.7.4.4.3 Configuration Options
 - 7.1.2.1.7.4.4.4 Improving PSA Recovery Efficiency
 - 7.1.2.1.7.4.4.5 Using a Membrane to Recover Hydrogen from Hydrotreaters
 - 7.1.2.1.7.4.4.6 Integrating PSA and Absorption Unit from Catalytic Reforming Unit
 - 7.1.2.1.7.4.4.7 PSA Using a Hydrogen-rich Feed Gas
 - 7.1.2.1.7.4.4.8 Comparison of PSA, Membrane, and Cryogenic Recovery Technologies
 - 7.1.2.1.7.4.5 Energy Consumption and Environmental Impact
 - 7.1.2.1.7.4.5.1 Factors Impacting Energy Efficiency and CO₂ Emissions
 - 7.1.2.1.7.4.5.2 Steam-reforming Designs with Heat Integration
 - 7.1.2.1.7.4.5.3 Maintaining PSA Unit Efficiency and Adsorbent Life
 - 7.1.2.1.7.4.5.4 Reducing Export Steam Production
 - 7.1.2.1.7.4.5.5 CO₂ Removal Systems
 - 7.1.2.1.7.4.5.6 Impact of Feed on Steam Reformer CO₂ Emissions
 - 7.1.2.1.7.4.5.7 Tri-generation: Hydrogen, Steam, and Power to Lower GHG Emissions
 - 7.1.2.1.7.4.5.8 SMR for Hydrogen Production and CO₂ Recovery
 - 7.1.2.1.7.5 Conclusion
- 7.1.2.1.8 Sulfur Plant
 - 7.1.2.1.8.1 Acid-gas Removal
 - 7.1.2.1.8.2 Claus Process
 - 7.1.2.1.8.3 Tail-gas Treating
 - 7.1.2.1.8.4 Other Methods for Producing and Handling Sulfur
 - 7.1.2.1.8.5 Energy Efficiency Improvements
 - 7.1.2.1.8.5.1 Acid-gas Removal and Enrichment
 - 7.1.2.1.8.5.2 Claus Process
 - 7.1.2.1.8.5.3 Tail-gas Treatment

- 7.1.2.1.8.6 Steam Production and Export
 - 7.1.2.1.8.7 Technology Innovations in Decarbonization
 - 7.1.2.1.8.7.1 Bio-desulfurization
 - 7.1.2.1.8.7.2 Simultaneous SO₂-CO₂ Removal
 - 7.1.2.1.8.7.3 Advanced Process Control and Simulation
 - 7.1.2.1.8.7.4 Adopting IoT in SRU
 - 7.1.2.1.8.7.5 Sulfur to Power
 - 7.1.2.1.8.7.6 Carbon Capture
 - 7.1.2.1.8.8 Plant Practices and Operational Experiences
 - 7.1.2.1.8.8.1 Steam-system Integration
 - 7.1.2.1.8.8.2 Sulfur Recovery Unit
 - 7.1.2.1.9 Future Technology Trends
 - 7.1.2.1.9.1 Advanced Crude Sourcing and Blending Technologies
 - 7.1.2.1.9.2 Crude Supply Chain Optimization
 - 7.1.2.1.9.3 Advanced Blending and Real-time Optimization
 - 7.1.2.1.9.4 AI-driven Product Quality Control
 - 7.1.2.1.9.5 Automated Storage and Retrieval Systems
 - 7.1.2.1.9.6 Real-time Inventory Management
 - 7.1.2.1.9.7 Integrated Storage and Distribution Systems
 - 7.1.2.1.9.8 Predictive and Condition-based Maintenance
 - 7.1.2.1.9.9 Digital Maintenance Management Systems
 - 7.1.2.1.9.10 Robotics and Drones for Inspections
 - 7.1.2.1.9.11 AI-powered Safety Monitoring Systems
 - 7.1.2.1.9.12 Wearable Safety Technology
 - 7.1.2.1.9.13 Virtual and Augmented Reality for Training
 - 7.1.2.1.9.14 Real-time Safety Dashboards and IoT Monitoring
 - 7.1.2.1.9.15 Safety and Maintenance Synergy through Digitalization
- 7.2 REFINERY DIGITALIZATION, INTERNET OF THINGS, AND ARTIFICIAL INTELLIGENCE**
- 7.2.1 Market Conditions**
 - 7.2.2 Technology Competition**
 - 7.2.3 Commercial Technologies**
 - 7.2.3.1 Digitalization
 - 7.2.3.2 IIoT Platforms and Ecosystems
 - 7.2.3.3 Implementation of the IIoT
 - 7.2.3.4 Asset Performance Management
 - 7.2.3.5 Cybersecurity Solutions
 - 7.2.4 Plant Practices and Operational Experience**
 - 7.2.4.1 Digital Transformation
 - 7.2.4.2 Green and Renewable Fuels
 - 7.2.4.3 Sensors and Control Valves
 - 7.2.4.4 Analytics and Digital Twin Technology
 - 7.2.4.5 Energy Management and Optimization
 - 7.2.4.6 Cybersecurity
 - 7.2.5 Future Technology Trends**
 - 7.2.5.1 Data-driven Refinery Operations
 - 7.2.5.2 Continuous and Real-time Monitoring Systems
 - 7.2.5.3 Big Data Analytics for Process Optimization
 - 7.2.5.4 Predictive Maintenance and Fault Detection
 - 7.2.5.5 AI and Automation in Refining
 - 7.2.5.6 Integration of IIoT with Edge Computing
 - 7.2.5.7 Cloud Computing for Remote Operations
 - 7.2.5.8 Energy Optimization and Sustainability
 - 7.2.5.9 Digital Twins for Enhanced Operations
 - 7.2.5.10 Conclusion

7.3 SUSTAINABILITY PROGRAMS TO INVEST IN PRODUCTS IN DEMAND AND RENEWABLE FUELS

7.3.1 Blue and Green Hydrogen Production

- 7.3.1.1 Market Conditions and Outlook
- 7.3.1.2 Commercial and Near-commercial Technologies
- 7.3.1.3 Plant Practices and Operational Experience
- 7.3.1.4 Future Technology Trends
- 7.3.1.5 Conclusion

7.3.2 Refinery-petrochemical Integration and Crude-to-chemicals

- 7.3.2.1 Market Conditions and Outlook
- 7.3.2.2 Commercial Technologies
- 7.3.2.3 Future Technology Trends

7.3.3 Lubricants/Lube Oil/Base Oil Production

- 7.3.3.1 Market Conditions and Outlook
- 7.3.3.2 Commercial Technologies
- 7.3.3.3 Commercial Processes
- 7.3.3.4 Plant Practices and Operational Experience
- 7.3.3.5 Future Technology Trends
- 7.3.3.6 Conclusion

7.3.4 Anode Coke/Graphite and Needle Coke Production

- 7.3.4.1 Market Conditions and Outlook
- 7.3.4.2 Commercial Technologies
- 7.3.4.3 Plant Practices and Operational Experience
- 7.3.4.4 Future Technology Trends
- 7.3.4.5 Conclusion

7.3.5 Biodiesel, Renewable Diesel, and Sustainable Aviation Fuel

- 7.3.5.1 Market Conditions and Outlooks
 - 7.3.5.1.1 Types of Biofuels
 - 7.3.5.1.2 Biofuels Mandates and Regulatory Incentives
 - 7.3.5.1.2.1 North America
 - 7.3.5.1.2.2 Latin America
 - 7.3.5.1.2.3 Europe
 - 7.3.5.1.2.4 Middle East
 - 7.3.5.1.2.5 Africa
 - 7.3.5.1.2.6 Asia-Pacific
 - 7.3.5.1.2.7 Conclusion
 - 7.3.5.1.3 Sustainable Aviation Fuel
 - 7.3.5.1.3.1 North America
 - 7.3.5.1.3.2 Latin America
 - 7.3.5.1.3.3 Europe
 - 7.3.5.1.3.4 Middle East
 - 7.3.5.1.3.5 Africa
 - 7.3.5.1.3.6 Asia-Pacific
 - 7.3.5.1.3.7 Conclusion
 - 7.3.5.1.4 Refinery Integration and Coprocessing
 - 7.3.5.1.4.1 Biomass Feedstock Considerations
 - 7.3.5.1.4.1.1 Diverse Biomass Feedstock Options and their Impact
 - 7.3.5.1.4.1.2 Technological Advancements in Biomass Conversion
 - 7.3.5.1.4.2 Effective Integration of Biomass into Petroleum Refineries
 - 7.3.5.1.4.2.1 Fluid Catalytic Cracking
 - 7.3.5.1.4.2.2 Hydrocracking
 - 7.3.5.1.4.2.3 Hydrotreating
 - 7.3.5.1.5 Technology Directions, Competition, and Future Prospects
 - 7.3.5.1.5.1 Commercial Processes for Biofuels or Bio-oil Production
 - 7.3.5.1.5.2 Research and Development Agreements and Emerging Processes

- 7.3.5.1.5.3 Current and Future R&D Trends
- 7.3.5.1.5.4 Recent Biofuels Construction Projects
- 7.3.5.1.6 Conclusion
- 7.3.5.2 Commercial Technologies
 - 7.3.5.2.1 Commercial and Emerging Processes
 - 7.3.5.2.1.1 Biodiesel Production
 - 7.3.5.2.1.2 Renewable Diesel Production
 - 7.3.5.2.1.3 Sustainable Aviation Fuel Production
 - 7.3.5.2.1.4 Summary of Commercial and Emerging Processes
- 7.3.5.3 Future Technology Trends
 - 7.3.5.3.1 Biomass/Lipid Conversion
 - 7.3.5.3.2 Biomass/Lipid Coprocessing with Petroleum Feeds
 - 7.3.5.3.3 Bio-oil Conversion
 - 7.3.5.3.4 Conclusion
- 7.3.6 E-fuels**
 - 7.3.6.1 Market Prospects and Applications
 - 7.3.6.2 Electricity Generation
 - 7.3.6.3 Shipping and Aviation
 - 7.3.6.4 Challenges and Opportunities
 - 7.3.6.5 Petroleum Refiners' Role in the E-fuel Future
 - 7.3.6.6 E-fuel Projects Undertaken by Energy Firms and Major Technology Developers.
 - 7.3.6.7 Conclusion
- 7.4 LOW-CARBON-INTENSITY AND CARBON-NEUTRAL CRUDES**
 - 7.4.1 Quality Characteristics of Select Crudes**
 - 7.4.2 Production of Low Carbon Intensity Crudes**
 - 7.4.2.1 Factors Affecting Carbon Intensity
 - 7.4.2.2 Carbon Intensity Calculation
 - 7.4.2.3 Availability
 - 7.4.2.4 Profitability and the Impact of Oil Demand Drops
 - 7.4.3 Industry Efforts to Drive for Lower Carbon Crude: Methods, Regulations**
 - 7.4.4 Conclusion**
- 7.5 ELECTRIFICATION, COGENERATION/CHP/IGCC/ AND ZERO-/LOW-CARBON FUELS**
 - 7.5.1 Electrification**
 - 7.5.1.1 Market Trends and Opportunities
 - 7.5.1.2 Technology Innovations
 - 7.5.2 Cogeneration, Combined Heat and Power, Integrated Gasification Combined Cycle**
 - 7.5.2.1 Cogeneration
 - 7.5.2.2 Combined Heat and Power
 - 7.5.2.3 Integrated Gasification Combined Cycle
 - 7.5.3 Combustion Using Zero-carbon or Low-carbon Fuels**
 - 7.5.3.1 Biofuels
 - 7.5.3.2 Biomass
 - 7.5.3.3 E-fuels
 - 7.5.3.4 Green Hydrogen
 - 7.5.3.5 Technical and Implementation Challenges
 - 7.5.3.6 Regulatory and Policy Factors
 - 7.5.4 Conclusion**
- 7.6 CARBON CAPTURE (UTILIZATION) AND SEQUESTRATION**
 - 7.6.1 Commercial and Emerging Carbon-capture Technologies**
 - 7.6.1.1 Combustion
 - 7.6.1.2 Fluid Catalytic Cracking
 - 7.6.1.3 Hydrogen Production
 - 7.6.1.4 Carbon Capture from Ethylene Plants
 - 7.6.2 Plant Practices and Operational Experiences in Carbon Capture (Utilization) and Sequestration**

- 7.6.2.1 Stepwise Approach for Refinery Carbon Capture
- 7.6.2.2 Amino-acid salts for CO₂ Capture
- 7.6.2.3 Carbon Capture with Flue-gas Heat Recovery
- 7.6.2.4 Optimizing CO₂ Capture from Syngas
- 7.6.2.5 Lowering Emissions from a Hydrogen Plant with CO₂ Capture

7.6.3 CC(U)S Projects and Demonstrations at Refineries

- 7.6.3.1 The United States
- 7.6.3.2 Canada
- 7.6.3.3 Latin America
- 7.6.3.4 Western Europe
- 7.6.3.5 Central and Eastern Europe
- 7.6.3.6 Middle East
- 7.6.3.7 Africa
- 7.6.3.8 Asia-Pacific

7.6.4 Direct Air Capture

7.6.5 Conclusion

7.7 ENVIRONMENTAL CONTROLS IN FLUE-GAS RELEASES, FLARING AND GHG EMISSIONS, AND WASTEWATER TREATMENT

7.7.1 Flue-gas Releases, Flaring and GHG Emissions

- 7.7.1.1 Commercial Technologies
- 7.7.1.2 Plant Practices and Operational Experiences
- 7.7.1.3 Conclusion

7.7.2 Wastewater Treatment

- 7.7.2.1 Resource Recovery and Circular Economy Integration
- 7.7.2.2 Advancements in Treatment Technologies
- 7.7.2.3 Digitalization and Optimization
- 7.7.2.4 Adapting to the Challenges of Renewable Diesel Wastewater
- 7.7.2.5 Conclusion

SECTION 8 STRATEGIC ANALYSES AND RECOMMENDATIONS

8.1 INTRODUCTION

8.1.1 Threats

- 8.1.1.1 Immediate and Long-term Market Threats for Global Refiners
- 8.1.1.2 Increasingly Stringent Climate Legislation and Evolving Regulations
- 8.1.1.3 Government Policies and Potential Impacts
- 8.1.1.4 Uncertainties over Carbon Credits
- 8.1.1.5 Public Pressure and Investor Demand to Decarbonize
- 8.1.1.6 Industry Trends of Resetting Green Ambitions amid Policy Shifts
- 8.1.1.7 Urgency and Uncertainty: Refining Competition in a Shifting Green Landscape
- 8.1.1.8 Oil Industry Faces Funding Considerations by Financial Institutions
- 8.1.1.9 Poor Profits Force Refinery Closures
- 8.1.1.10 Challenges to Petrochemical Imports and Exports due to Potential Trade Wars
- 8.1.1.11 Diminishing Demand for Traditional Transportation Fuels
- 8.1.1.12 Competition from Alternative Fuels

8.1.2 Opportunities

- 8.1.2.1 Immediate and Long-term Opportunities for Global Refiners
- 8.1.2.2 Navigating Shifting Green Policies amid Trade Wars
- 8.1.2.3 Gains amid Closures: Opportunities for Surviving Refineries in a Consolidating Market
- 8.1.2.4 Increasing Demand for Petrochemicals and Graphitic Coke: Opportunities and Challenges
- 8.1.2.5 Emerging Opportunities in Renewable Energy
- 8.1.2.6 Impetus to Transform Business, Enter New Markets, and Form Partnerships

8.2 MICROSCOPIC ANALYSES: REFINERS' ATTRIBUTES

8.2.1 Weaknesses

- 8.2.1.1 Financial Burden and Time Pressure
- 8.2.1.2 Limited Capital Funding due to Financial Institutions' ESG Lending Requirements
- 8.2.1.3 Demand Decline and Weak Financial Performance Impacting Refining Business
- 8.2.1.4 Obstacles to Modify Existing Processing Units to Reduce Carbon Footprint
- 8.2.1.5 Crude Supply Shifts and Search for Low-carbon-intensity Crudes
- 8.2.1.6 Availability of Renewable Feedstocks to Make Low-carbon Fuels

8.2.2 Strengths

- 8.2.2.1 Technical Expertise and Resources
- 8.2.2.2 Financial Incentives, Subsidies, and Support
- 8.2.2.3 Opportunities to Improve Current Efficiency and Productivity
- 8.2.2.4 Revamp Approach: Integration of New Low-emission Units into Existing Operations
- 8.2.2.5 Refiners Positioning to Counter Competition from EVs and Alternative Fuels

8.3 RECOMMENDATIONS

8.3.1 Strategic Energy Transition and Decarbonization Planning

8.3.2 Enhancing Operational Efficiency and Emissions Control

8.3.3 Using Latest Refinery Decarbonization Technologies

8.3.4 Modifications of Existing Refinery Facilities to Meet Future Demand and Sustainability

8.3.5 Diversification and New Revenue Streams

8.3.6 External Drivers and Implementation Considerations

8.3.7 Building Flexibility and Resilience for Short-term Uncertainties and Long-term Sustainability

- 8.3.7.1 Agile and Scenario-based Strategic Planning
- 8.3.7.2 The Path Forward: Adapting to Uncertainty
- 8.3.7.3 Modular and Phased Investment in Decarbonization Technologies
- 8.3.7.4 Diversification of Product Portfolio and Revenue Streams
- 8.3.7.5 Strategic Partnerships and Collaborations
- 8.3.7.6 Robust Financial Planning and Risk Management

SECTION 9 REFERENCES