Sustainability, Decarbonization and Industry Initiatives: Survey Findings and Analysis

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Executive Summary

With increasing momentum over the past 12 months, the global energy and chemical industries have embraced sustainability by setting ambitious and broad carbon mitigation, plastics re-use and water conservation targets. What is driving this momentum? What initiatives are companies investing in to move toward these targets? To what extent is industry looking at this in the short and long term? Where is there consensus or divergence in approaches? And when looking at the convergence of sustainability and technology, where are the greatest opportunities for innovation and collaboration?

To address these questions, we surveyed 340 industry executives and senior managers on a range of questions related to sustainability in general and carbon mitigation in particular. Many of the answers we received confirmed publicly available information. But in some areas we learned that the extent of the commitment to sustainability is more pronounced than generally understood. And there are a few areas of particular insight.

First, respondents are generally pursuing a range of sustainability strategies, rather than a singular approach. Before deciding on where to invest, many companies are intending to follow closely a smaller number of first movers and innovators. But one of the most interesting findings is the initiatives attracting the most focus and investment (see summary of these focus areas in Figure 1). In particular, hydrogen and carbon capture are two of the four most frequently cited initiative areas, and every company surveyed is pursuing energy optimization and conservation initiatives. Energy source transition to renewables is also a big investment area.

Sustainability Investments Over Time

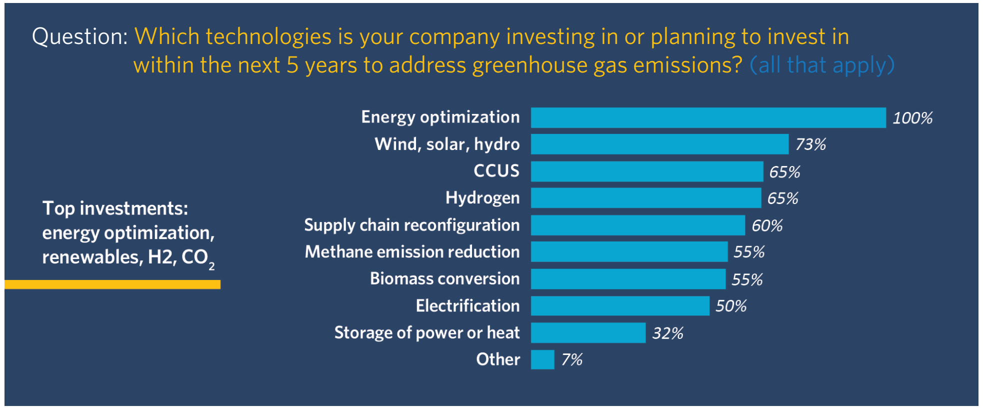

Figure 1. Which technologies are you investing in/planning to invest in over the next five years to address greenhouse gas emissions?

Despite regional differences in governmental sustainability goals and regulatory frameworks, the level of industry commitment to sustainability progress is consistent worldwide. This is reflected in the views on how sustainability is impacting industry by region (see Figure 2).

Globally >60% Companies Anticipate Significant Sustainability Impact

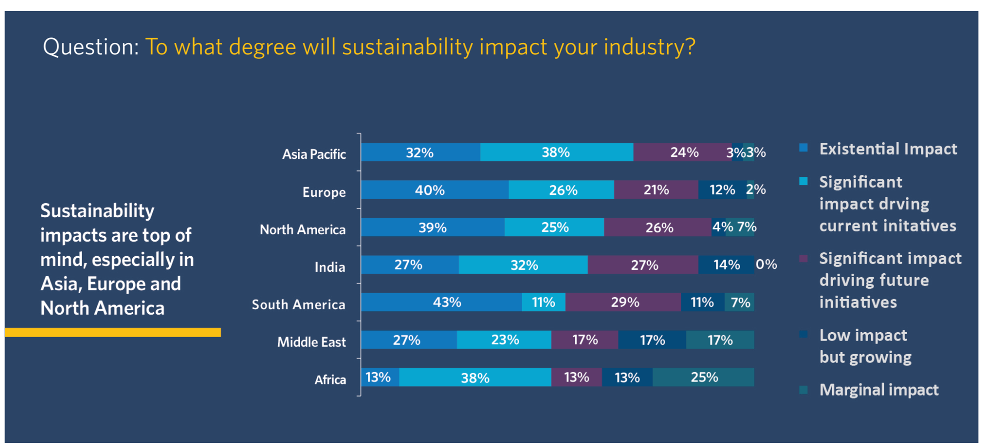

Figure 2. Sustainability impacts on asset-intensive industries by region.

We begin our discussion with an overview of climate change and carbon mitigation science. We then look at approaches to measurement and metrics of carbon emissions, review alternatives for mitigation, cover industry and regional differences, and summarize how technology is and will play a role in the next several years.

Why Net Zero? The Global Carbon and Climate Change Picture

A deep idea underlies "climate change," which is that ordinary human activity can create problems for human well-being, at a planetary scale and extending far into the future. Human activity is no longer too puny to have global impacts. Until recently (about 50 years ago), the realization that we can foul our own nest globally was hardly ever even imagined. In the case of climate change, the most relevant human activity is the burning of fossil fuels, which currently results in about 35 billion tons of carbon dioxide emissions entering the atmosphere every year, approximately one percent of the stock of carbon dioxide in the atmosphere. The amount of carbon dioxide in the atmosphere is actually growing about half that fast right now, about one-half percent per year, because carbon dioxide is also being removed from the atmosphere at the ocean's surface and by vegetation.

Ample evidence confirms that adding carbon dioxide to the atmosphere raises the Earth's average surface temperature. A useful approximate relationship is that for every 1600 billion tons of CO_2 added to the atmosphere, the Earth's average surface temperature will rise one degree Celsius. The left half of the triangle in Figure 3 shows an idealized representation of the fossil fuel era's carbon dioxide emissions to date, rising linearly over 80 years to its current rate (rounded off to 40 billion tons per year), during which period the Earth's surface temperature did indeed rise about one degree Celsius. The right half of the triangle shows how a "two-degree" global temperature might be achieved, where the fossil fuel emissions rate era descends at the same rate as it grew. Emissions in 40 years (half-way down) would be half of those at this time.

The schematic representation in Figure 3 is an approximation but adequate to illustrate the CO_2 dynamics in the atmosphere. The uncertainties in the relationship between atmospheric carbon dioxide and surface temperature are not well enough pinned down to know them exactly. Accordingly, we don't know how quickly bad things will happen. There is a 1/6 chance of being unlucky and getting three degrees or more of warming while achieving what today is considered the two-degrees target. Similarly, there is a 1/6 chance of being lucky and getting two degrees or less of warming while achieving what today would be considered an irresponsible three-degrees target. Although uncertainty of this sort is sometimes invoked as an argument for delaying the kinds of climate policies that would reduce emissions, the argument goes the other way: the more incomplete our understanding of how soon bad outcomes will arrive, the stronger the case for moving boldly. The goal of the 2014 Paris Agreement is to stay "well below" 2ºC of warming of the Earth's average surface temperature, relative to its value in 1800, which requires lowering global emissions at mid-21st century by more than half.

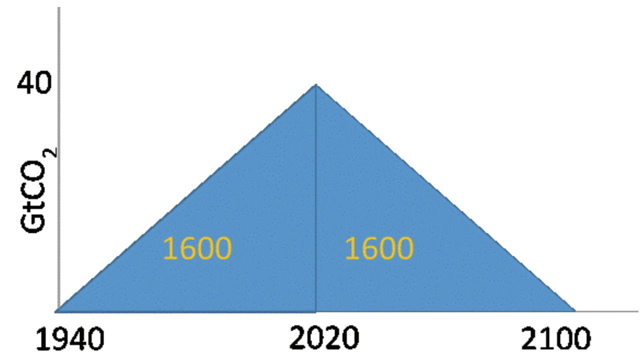

Figure 3. Approximate carbon emissions trajectory for a hypothetical "2º C" cap on the rise in the average temperature on the Earth's surface, relative to its pre-industrial value. Both half-triangles have areas of 1600 billion tons of carbon dioxide ($GtCO_2$), which is approximately associated with one degree Celsius of temperature rise. [Source: Robert Socolow, 2021]

Even stronger goals are now being discussed by some governments and environmental interest groups, such as achieving "net zero" emissions in 2050. These are likely to be debated at the 2021 Glasgow Climate Change Conference (COP26, early November, 2021).

Human populations are particularly vulnerable to planetary changes because our planet's climate was relatively stable over the past five thousand years. Agriculture could proceed at well-suited locations, and cities could sit close to the edge of the sea. This period has been anomalous: over the past 20,000 years, as the world exited from an ice age, sea level rose more than 100 meters. A mere two meters of further sea level rise, were it to occur over this century, would create severe displacement of communities. For example, in the United States, much of southern Florida would be under water. The extraction of fresh water from aquifers contributes to the subsidence that increases the rate of relative sea level rise with increased flood risk. Two meters of sea level rise by 2100 is greater than the experts' central estimate, but this outcome when retaining today's version of the fossil fuel economy is credible. (A rising temperature at the Earth's surface melts the ice on glaciers and ice sheets, and the meltwater finds its way to the sea.)

Dividing the 35 billion tons of global carbon dioxide emissions per year by the world's population of about 7 billion people, each person's "share" of global emissions is about five tons of carbon dioxide per year. Figure 4 shows four everyday personal activities, each of which on its own adds carbon dioxide to the atmosphere at that rate. The average American emits about 15 tons of CO_2 per year, the average European and the average Chinese about 10 tons per year. Greater efficiency in uses of energy (more efficient vehicles and better designed houses, for example) can reduce emissions dramatically, but quickly moving away from the current fossil fuel energy system to an alternative energy source is clearly going to be required if we hope to bring the growth of fossil fuel emissions to a halt and phase out nearly all uses of fossil fuels.

Impact of Everyday Activities on CO_2 Levels

The following chart compares how four different activities can impact yearly CO_2 emissions.

Activity	5 ton CO_2/year emissions
a) Drive	30,000 km/year @ 5 liters/100km (45 mpg)
b) Fly	30,000 km/year
c) Heat home	Natural gas, average house and climate
d) Lights	400 kWh/month, all coal-power 800 kWh/month, all natural-gas-power

Figure 4. Four ways to emit five tons of CO_2/year (today's global per capita average).

In addition to carbon dioxide, today's energy and chemicals producers are confronting emissions from a second greenhouse gas, methane. Methane produces about half as much warming as carbon dioxide today. The percentage growth rates of methane and carbon dioxide emissions are similar, about one-half percent per year. Today's levels are a higher multiple of their pre-industrial value, 2.5 times greater for methane vs. 1.5 times greater for carbon dioxide. Per ton, adding methane is 100 times more consequential for global warming at the time of emission, but methane's average residence time in the atmosphere is about 12 years before it reacts with other components of the atmosphere, while a significant fraction of carbon dioxide stays in the atmosphere indefinitely. So from a century-scale perspective, methane emissions are relatively less consequential than from an instantaneous perspective. The upshot is that there is no one answer to the relative impacts of carbon dioxide and methane; it depends on the timeframe being considered. If you focus on a 100-year timeframe (appropriate for predicting future sea level rise), today's methane emissions will be less important relative to today's carbon dioxide emissions than if you focus on a 20-year timeframe (appropriate for contending with the prospect of extremes of weather).

Importantly, fossil fuels are the largest source of human-induced carbon dioxide emissions, with deforestation in second place, while the relative ordering is reversed for methane. For fossil fuels, a rule of thumb (albeit with considerable uncertainty) would assign 80 percent of human-generated carbon dioxide emissions to fossil fuels and 20 percent to biological sources like deforestation, but 80 percent of methane emissions to biological sources and 20 percent to leakage in the system of natural gas extraction, distribution, and use. Of course, methane captured rather than leaked into the atmosphere can be sold into a huge commercial market, while only small quantities of carbon dioxide can be sold at this time.

Survey Methodology

In the fall of 2020, AspenTech conducted a survey of industry executives and operational leaders across leading companies representative of asset-intensive industries (oil and gas, refining, chemicals, mining, power, pharma and consumer goods). We received 340 responses, with 183 respondents completing the entire survey. We incorporated partially completed responses in the results. The responses we received were well distributed among industry sectors and geographies (see Figure 5). As a follow-up, we conducted personal interviews with a small number of respondents to better understand some of the thinking behind the ways companies responded to the survey.

Demographics of Survey Respondents

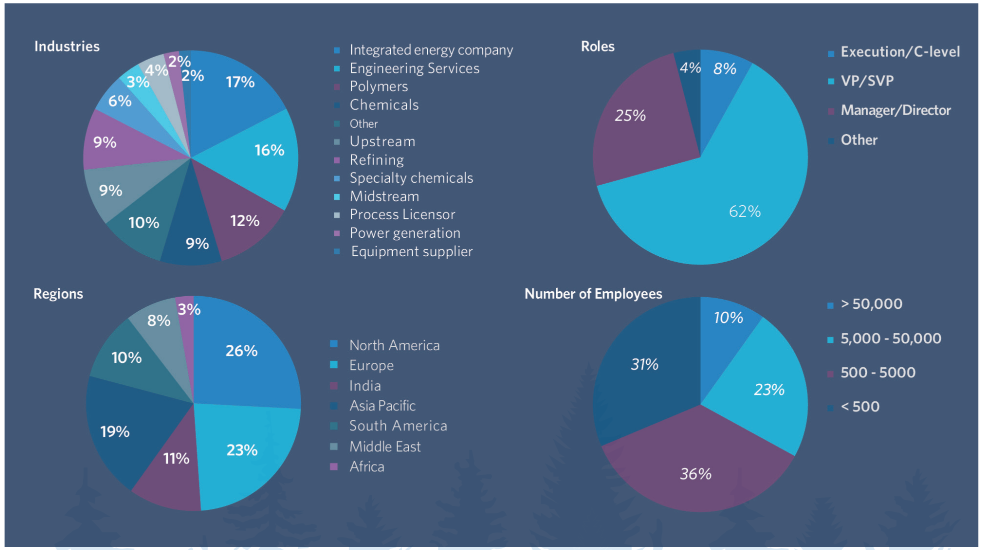

Figure 5. Demographics of respondents to the 2020 AspenTech Sustainability Survey.

How Transparent Are Sustainability Goals?

In our recent survey, 92 percent of the individuals responding to the survey indicated that they were involved with, or had visibility into, sustainability initiatives within the company, and most of the respondents were director level or higher within their companies. This data suggest that sustainability is no longer solely the purview of an ESG officer or department, but rather broadly the responsibility of operations staff in industries such as oil and gas, refining and chemicals while also being embedded deeper in the organization.

92% of Respondents have Visibility into Corporate Sustainability Goals

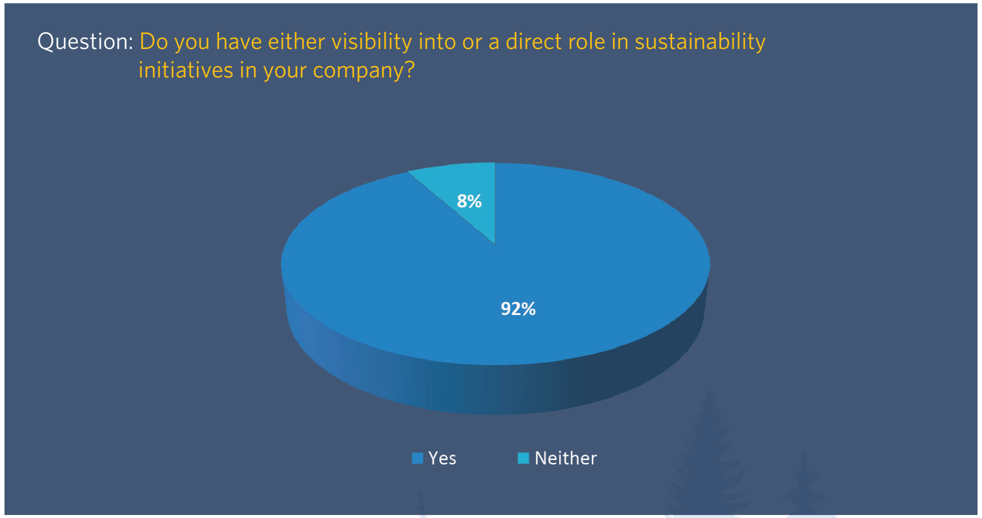

Figure 6. Transparency of corporate sustainability goals.

Motivation for Change

The growing understanding and recognition of the importance of carbon mitigation, explained above, is becoming clear at governmental, community, investor and industry levels. We wanted to know if companies are addressing sustainability solely due to government policy or investor pressure. The reasons most responsible for driving industry action are in fact much broader than that (see Figure 5).

When viewed broadly, the graphic illustrates the point that government policy, societal obligations, new market opportunities and customer pressures are key factors influencing company actions related to carbon mitigation and sustainability. There are some subtle differences by industry sector, in terms of the forces driving sustainability action.

Government, Societal and Business Factors Drive Sustainability

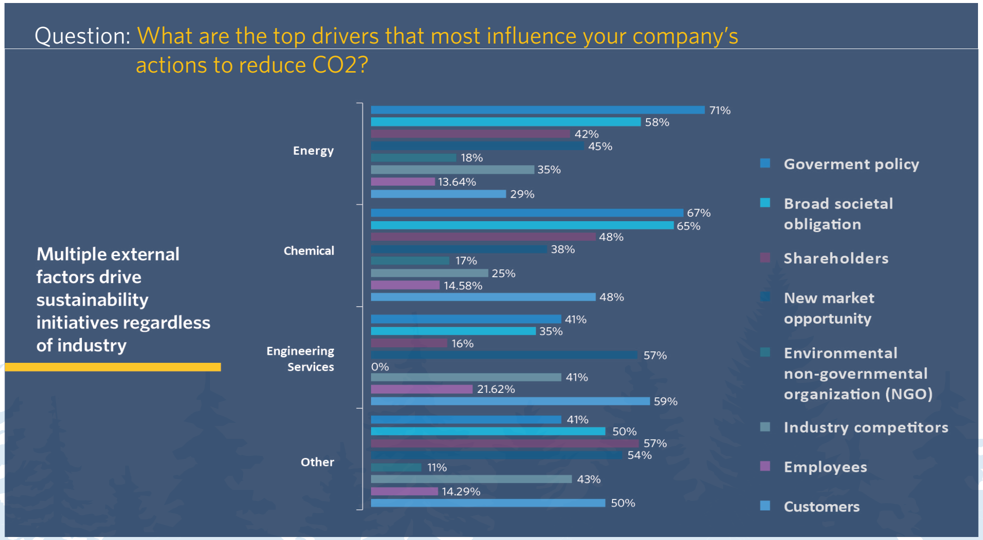

Figure 7. Factors influencing industry to focus on CO_2 reduction across assets and supply chains.

For example, in the chemical sector, customers and societal obligation score higher as driving factors. In the engineering and construction (EPC) sector, customers are the primary driving factor, suggesting that EPC firms are seeing signals that much of their future project business will be sustainability related. One CEO of an engineering firm told us, "I spent much of my time thinking about sustainability at my level. It is driving customer project work, both in terms of which assets they are no longer going to invest in or even to divest, and in terms of the opportunity to perform projects in areas such as green and blue hydrogen and ammonia."

It is readily apparent that the driving factors for sustainability investment go beyond governmental policy, and are seen by many as critical to a thriving future business. This notion was further confirmed with another question, which asked people if they view carbon reduction as providing a competitive marketplace advantage. An overwhelming 78 percent of respondents agreed that a CO_2 reduction strategy has provided a significant or moderate advantage for their company. (see Figure 8).

78% See CO_2 Reduction as a Competitive Advantage

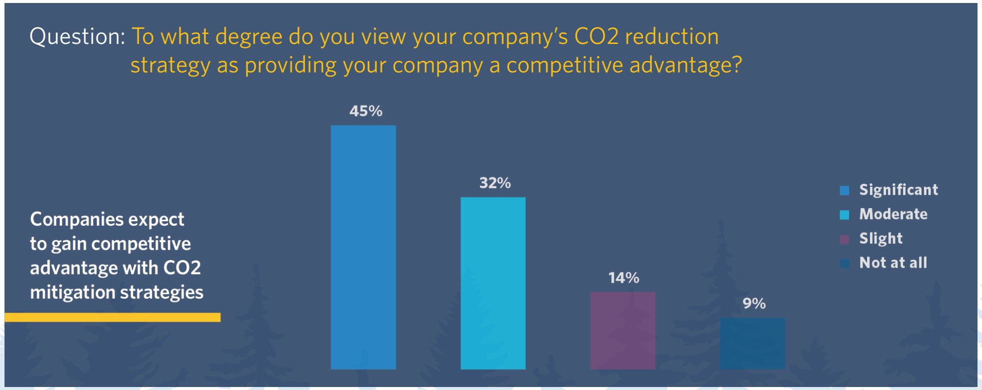

Figure 8. CO_2 reduction strategies will also provide companies a business edge.

Measurement and Metrics

You can't improve what you can't measure is a common mantra of management consultants. Nowhere is this more true than when considering the drive toward sustainable industrial companies. When an organization makes a pledge to reduce carbon emissions, reduce water use, or reduce plastic waste by a target percent, how do you calculate your baseline references to compare future changes against? And how do you chart progress so that managers and workers can take timely action? We were curious how companies measure that.

It's a complicated question as different companies have assets of different ages and widely varying capabilities to measure progress, including instrumentation, sensors, lab testing and digital twins. As one example of the disparity in measurement: An analysis of published company ESG and investor reporting identified baseline dates when reporting carbon emissions improvements that varied greatly from 2007 to 2020.

Top Sustainability Metrics

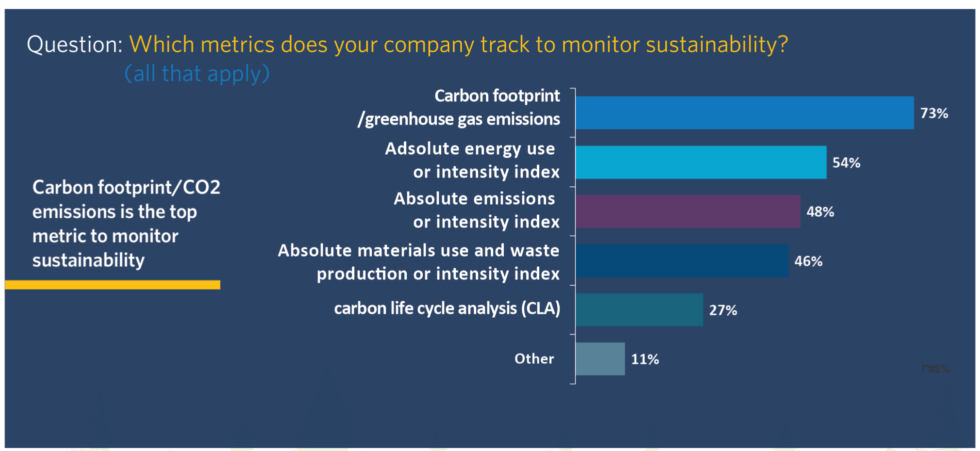

Figure 9. Sustainability metrics reported by respondents to the Sustainability Survey.

We asked several questions in the survey to gain some useful insights across the spectrum of industry situations.

Survey responses indicate that a relatively small number of companies are performing total carbon lifecycle analysis of their products, and have mixed intent to measure progress with simple (but hard to standardize) measures of "carbon footprint," such as energy, emissions, and waste use or intensity. Only 27 percent of companies are evaluating the full carbon lifecycle while 46 percent are tracking materials use and waste production. Additionally, a surprisingly low 54 percent of respondents said they are tracking absolute energy use or energy intensity within their operations (see Figure 9).

In a conversation with the Kline Group (August 2021), they indicated that interviews with leading global chemical providers found that company executives today feel handicapped by a perceived lack of consistent and standardized tools and methods to assemble and report on total carbon emissions by an organization. They also feel more challenged in terms of the ability to look at lifecycle analysis in a consistent way across a value chain that would include suppliers and customers.

The objectives of good measurements go beyond those desired previously, in that they must also meet needs for transparency and persuasiveness in enabling the increased appetite for inspection by investors, regulators, policy-making bodies, employees, the public and sustainability interest groups.

Technology approaches used today in performing the task of measuring and understanding carbon emissions were identified by survey respondents, as shown in Figure 10. The results illustrate a range of approaches by organizations as well as a range of maturity levels in their ability to measure, report and predict outcomes. Almost 50 percent of respo dents report that their companies measure CO_2 emissions indirectly, using reference values; while only 30 percent indicate that they are measuring CO_2 will a fully systematic approach.

CO_2 Measurements

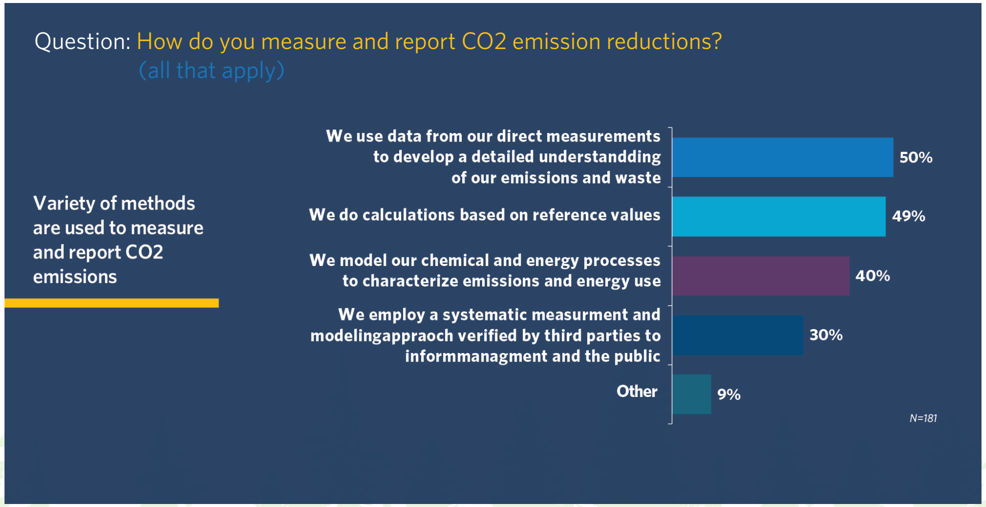

Figure 10. CO_2 emissions measurement and reporting methods of survey respondents.

Companies are looking for consistent measurement and reporting methods to be used across the industry, in order to effectively incorporate carbon intensity into procurement processes and products to enable green marketing approaches. Investors are looking for transparency and accuracy in reporting to evaluate company performance against promised carbon mitigation and sustainability targets that have been reported to the financial markets.

Low Carbon Energy

Widening our view to a 30,000-foot perspective, the energy system continues to be dominated by fossil fuels world-wide, but for the first time there is ferment in the energy sector related, ultimately, to a strengthened societal desire to slow the consequences of climate change. Our survey reveals that today, this is resulting in a range of low carbon energy initiatives across industry.

Following the emerging and impactful government policies in the European Union and California, it is anticipated that additional and more widely adopted policies will enable and financially encourage new processes, new industries, and, indeed, a swap of most of the current fossil-fuel energy system for low-carbon alternatives. It is not an exaggeration to say that societies are confronting unprecedented decisions about which fossil fuels to leave in the ground and, for the fossil fuel that continues to be produced, which uses to prioritize and which to find substitutes for.

The extent to which many of the alternatives are being considered by energy, chemical and other industrial companies was revealed in our survey, as the existing industry players seek to anticipate and incorporate those new alternatives within existing business frameworks (Figure 11). Transcending the distinctions between primary energy sources for the future is energy efficiency today. There are immense opportunities to provide energy services with lower energy demand by technological innovations. The LED lightbulb was a high-impact invention from the perspective of reduced greenhouse gas emissions, but largely unheralded. Technology has been contributing and will continue to contribute to the substitution of information technology for personal and business travel.

The road ahead has a fork, which is being described by new vocabulary. One fork (the "blue" fork) retains but reconfigures the fossil fuel economy. Central to the blue fork is the capture of the carbon in fossil fuels so that it never reaches the atmosphere. The other fork (the "green" fork) sets the fossil fuel economy aside. The blue encourages technology-neutral decarbonization; the green adds the objective of defossilization. Blue electricity is produced with natural gas or coal, supplemented with carbon dioxide capture and use or storage (CCUS): the capture (e.g., from flue gas) of the carbon dioxide combustion byproduct and either its storage (for at least centuries, e.g., in deep geological formations) or its incorporation into very long-lived products like building materials (thus far, not a large market). Similarly, blue hydrogen would be produced by the steam reforming of methane, with capture and either storage or use in long-lived products of the byproduct carbon dioxide (CCUS) as well as minimal leakage of methane. Ditto, blue ammonia (made from nitrogen and blue hydrogen) and blue carbon dioxide captured from the air (e.g., through processes powered by natural gas with (CCUS). Large scale blue hydrogen from natural gas will also involve capture and avoidance of fugitive methane emissions.

Sustainability Investments Over Time

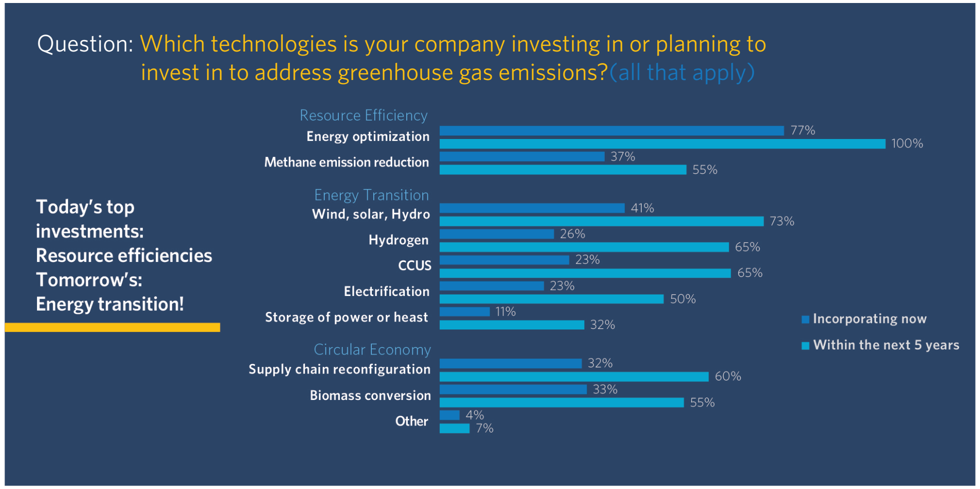

Figure 11. Within the next five years, over 65% of current industry players will be investing in renewables, in hydrogen economy, and in carbon capture.

The fossil fuel economy today, as noted above, injects about 35 billion tons of carbon dioxide into the atmosphere each year, and the scale of the blue portion of any future energy economy can be measured in terms of the total mass flow of carbon dioxide into the subsurface in these same units (neglecting use). Even one billion tons of carbon dioxide flowing back into deep aquifers is an immense flow. A representative density for this carbon dioxide (a supercritical fluid) is six tenths of the density of water, in which case the volume flow equivalent to a flow of one billion tons of carbon dioxide per year is a flow of 30 million barrels per day, about one and a half times the outward volumetric flow rate of oil from the subsurface in the United States at this time.

The Colors of the Energy Transition

Green:
(as applied to hydrogen, ammonia, and other energy transition approaches): Green hydrogen refers to hydrogen produced with zero greenhouse gas load, usually hydrogen derived from electrolysis of water, where the electricity source is a renewable such as solar, wind, or geothermal power conversion. (Of course, in a lifecycle analysis, the resource, environmental and energy cost of mining and production of batteries, solar panels, or wind turbine blades should be considered.)

Blue:
(as applied to hydrogen, etc.): Blue hydrogen or ammonia refers to synthesis from natural gas, usually via a reforming process, in which the CO_2 emitted from the synthesis process is captured by a carbon capture technology.

Grey:
Grey hydrogen applies to hydrogen synthesized from reforming of natural gas, but where CO_2 is emitted and not captured.

Brown:
Brown hydrogen applies to hydrogen synthesized via a coal conversion process.

The infrastructure required to collect, pipe and inject a small fraction of today's carbon dioxide production from fossil fuels is comparable to the infrastructure in place now to extract and distribute fossil fuels. Nonetheless, arguably, the blue economy is a critical component of the low-carbon economy.

The green approach to the low-carbon economy has no reliance on fossil fuels. It uses renewables to make electricity, to split water into hydrogen for industries and perhaps transport, and, someday, to power the removal of carbon dioxide from the air. Solar and wind power are the presumed workhorses of the green economy, supplemented by hydropower, biomass, geothermal power and ocean sources (waves, ocean thermal energy and tides). In one recent study a US economy dominated by solar and wind would have three million megawatts of installed wind + utility-scale solar, roughly half of each. To reach such an installed capacity by 2050 would require an average installation rate of about 100,000 MW/yr. By comparison, China installed 72,000 MW wind and 48,000 MW solar capacity in 2020.

The complications of solar and wind power arising from their variability are widely appreciated. The longer the period of variability, the larger the challenges to the energy system. Second to inter-seasonal variability is the variability of the long lull and the cloudy week. See Figure 12, which shows the aggregated hourly wind power production in the ERCOT service area in Texas in 2016, when the installed capacity was 17,000 megawatts and the annual average power output was 6,000 megawatts. Intervals A (four days) and B, C, and D (each, two days) mark the four longest periods when wind power output remained continuously below 3,000 megawatts: (half of the annual average). Providing week-long storage on the supply and demand side and supplemental power will be challenging.

Wind power is moving offshore and heading for ever deeper water. Here is where there is an obvious opportunity to transfer technology from the world of offshore oil and gas, which went through a similar transition three decades ago, as suggested in Figure 13.

Also under consideration are strategies that compensate for the warming effects of greenhouse gases by augmenting the reflection of incoming sunlight. Today, 31 percent of incoming sunlight is reflected, notably off the tops

The Challenge of the Long Lull and Cloudy Week

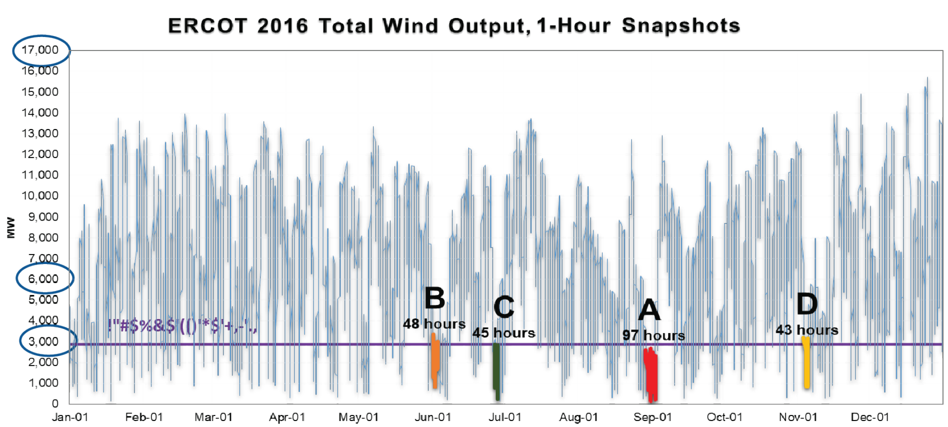

Figure 12. A, B, C, and D mark the four longest periods during 2016 when wind power output was continuously below 3000 megawatts (half of the 6000 megawatt annual average). The total installed capacity was 17,000 megawatts. (Figure and analysis courtesy of Pedro Haro.)

Evolution of Deep-Water Technology

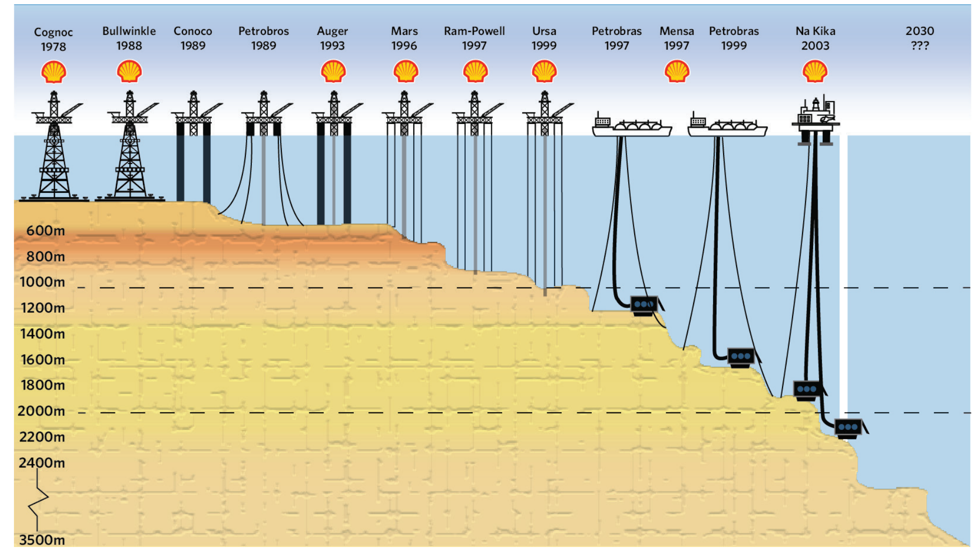

Figure 13. The march of oil and gas drilling platforms into ever deeper water in the quarter century from 1978 to 2003 may be repeated with wind-turbine platforms in the quarter century ahead. (Source: Antonio Pflueger, talk at Princeton, fall 2005.)

of clouds and off ice; raising that amount to 32 percent (by placing reflectors in the stratosphere, for example) would compensate for about one degree Celsius of warming. But the workings of our Earth would need to be much better understood before such "solar geoengineering" would be safe.

From a global perspective, enabling low-carbon industrialization in the currently industrializing countries has the highest priority, because these investments bring decade-scale to century-scale commitments to specific infrastructures (lock-in). The world is searching for mechanisms to share the costs of technological solutions that "leapfrog" over the tried-and-true solutions used in earlier industrialization. An example is the way China is transporting electricity at higher voltages than elsewhere in the world. Similar leapfrogging is urgently needed for urban apartment buildings and their appliances. In the U.S. today, 70 percent of power-plant electricity goes to buildings; less demand for heating, cooling, and appliance energy translates into fewer power plants. Figure 14 illustrates this message.

Scope Three emissions include emissions when products are used, as well as emissions associated with both upstream manufacturing sources (such as the fertilizers used to grow bio-feedstocks) and downstream emissions associated with product distribution. Scope One emissions occur at the sites where products are made, and Scope Two emissions occur at the places where energy (especially, electricity) is produced that is used in the production process. The sum of the three, along with emissions associated with disposal, are the product's Lifecycle emissions. For many industries, most emissions come from product use, not product creation. Gasoline-powered cars take energy to make, but the emissions associated with car manufacture (the car's Scope One and Two emissions) are much smaller than the emissions from the burning of gasoline over the car's lifetime (the car's Scope Three emissions).

Enormous opportunities to reshape public perceptions of the fossil fuel industries' agency in climate change might result if these industries were to make a concerted effort to reduce Scope Three emissions. Three examples of how a warmer welcome for blue solutions might emerge: 1.) odometers could be read at the gas station so as to provide miles-per-gallon information to customers who fill up reliably with the same brand of gas, 2.) the provider of natural gas to a new community could become involved with construction quality and 3.) fossil fuel producers could become engaged more directly in plastics disposal.

Figure 14. Industrialization in currently industrializing countries (the boy) must involve technologies never tried when today's already industrialized countries were industrializing (the girl). Such "leapfrogging" is scarcely happening yet in the immense sector of new multi-family housing. (Photo shows Yanjiao, China.)

Businesses based on fossil fuels are now searching for blue opportunties within the low-carbon economy more intensely than ever before. Yet there are already signs and a real future risk that low-carbon policy will favor the green over the blue. For blue to be rewarded, at least to the extent of color-neutrality, public trust must be earned at this time with actions such as investments in meaningful industrial-scale projects and independent auditing of net carbon impacts. Among the paths forward are those which provide transparency beyond standard procedures and monitoring for confidence building.

Tightening the entire natural gas system to improve full-system greenhouse gas accounting has a high priority. Loss-leader projects may be required that demonstrate the contributions to low-carbon objectives available from blue technology. The public must be persuaded, moreover, that blue projects won't be reversed—that fossil-energy projects designed with CCUS won't someday revert to projects with the catbon dioxide vented to the atmosphere.

Where are Companies Voting with their Capital Dollars?

The survey respondents are painting a picture of change, with significant investment in new energy options, but also uncertainty—energy and chemical companies are split roughly 50-50 between blue and green approaches. Figure 15 illustrates where companies are making their bets and it's readily apparent that there is no consensus as to whether blue or green hydrogen will be the winning approach.

An executive from a leading hydrogen company responded with an explanation of the trends they are seeing in the market and the directions they are pursuing. He noted, "There is still much more innovation being introduced which will significantly improve the efficiency, functionality and economics for both green and blue hydrogen." Another executive we spoke to at a leading Asian energy company told us, "There is an opportunity to differentiate in the market by driving the costs of these new technologies way down. Hydrogen has not yet been tackled seriously at scale yet."

A fundamental shift in capital spending is happening, with companies applying very significant investment capital toward sustainability-related initatives. Figure 16 illustrates the extent of the capital shift into sustainability areas—with 21 percent of respondents signifying a greater than 20 percent shift and 48 percent a 5-20 percent shift. Cumulatively, this will represent hundreds of billions of dollars shifted into carbon emissions reduction and mitigation. As global demand for resources increases, investment in traditional plant improvement may decrease in terms of percentage, but not in total dollar spend.

For those Investing in H2, Blue and Green H2 are Equally Important

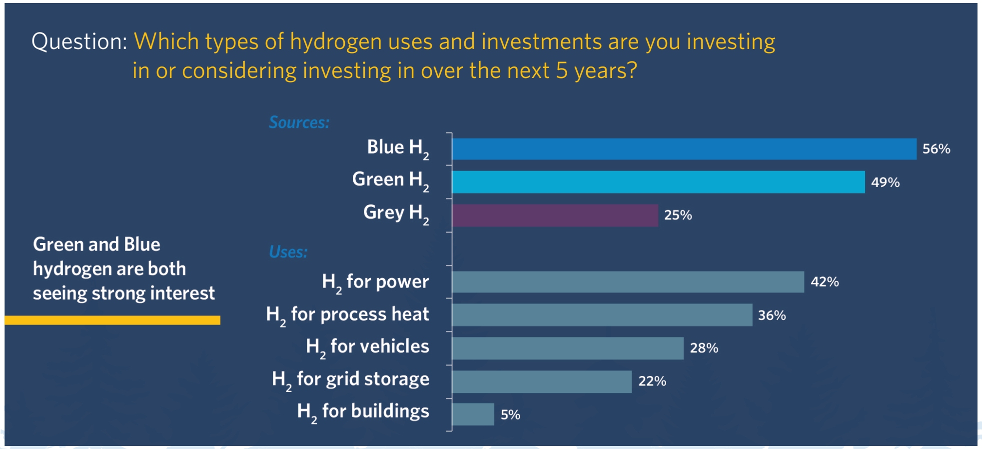

Figure 15. Hydrogen economy relative focus on green versus blue, and on hydrogen end uses.

Sustainability Drives Shift in Spending

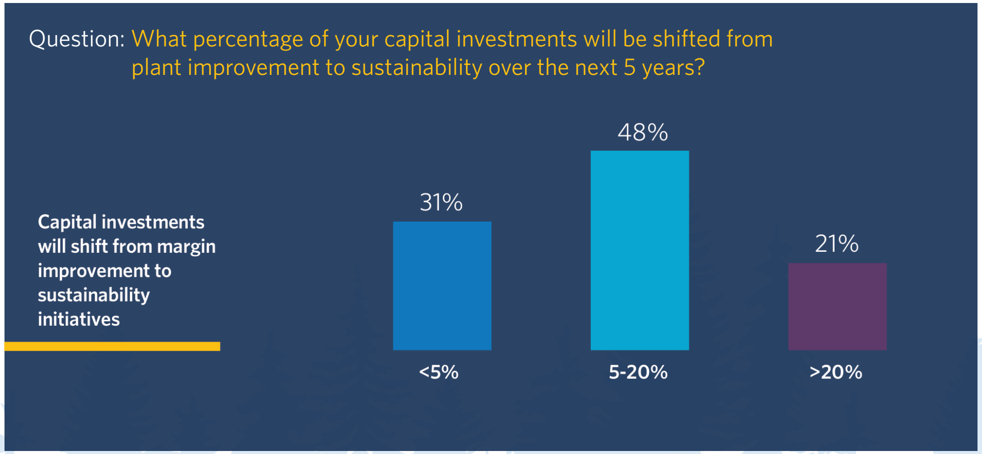

Figure 16. How capital spending is shifting towards carbon mitigation and energy transition.

Companies also report significant moves (55 percent) to invest in integrating alternative bio-based feedstocks in production of energy and chemicals.

The Role of Technology

With this shift in investments and initiatives, the next big challenge is accelerating innovation, driving economic maturity of these new energy strategies, and enabling adoption to reach the low carbon goal within the time deadlines that companies and governments have set (see Figure 17). Digital technology is positioned to be one of the most important enablers of this major inflection point, to both speed innovation and address the dual challenge of sustainability and growth in global demand for energy and materials. Additonally, digital capabilities are enabling companies to cut energy use and waste generation in current operations right now, as they optimize existing processes while exploring new options.

Nearly 60% will Repurpose Existing Infrastructure and/or Build New Assets

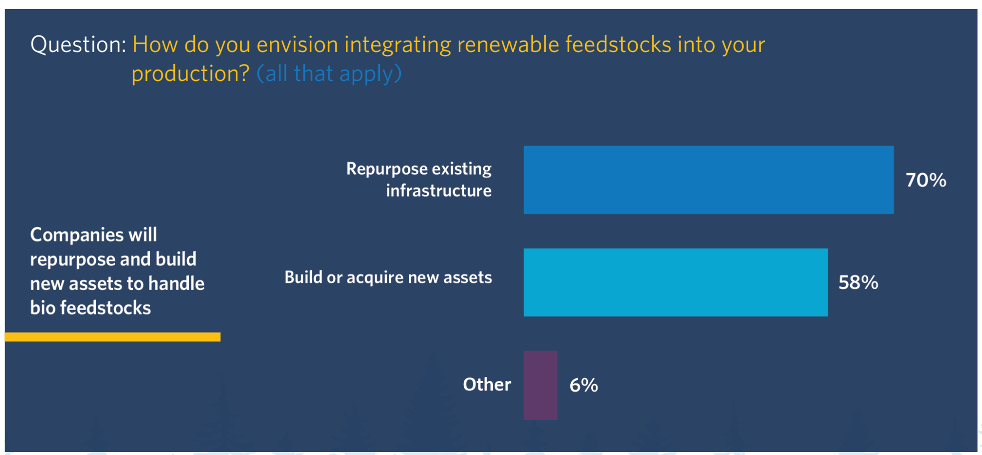

Figure 17. How capital spending is shifting toward carbon mitigation and energy transition.

Digital solutions that will help the most are those that enable techno-economic optioneering of new innovative processes, systems level tools that examine the viability and operational excellence of strategies in emerging areas (such as the hydrogen economy), and optimization tools powered by industrial AI that assist organizations in addressing economic and sustainability success simultaneously.

Figure 18 demonstrates how these key digital solutions map to the decarbonization and sustainability initiative areas that companies identify they are investing in.

Sustainability Initiatives Mapped to Technology Solutions

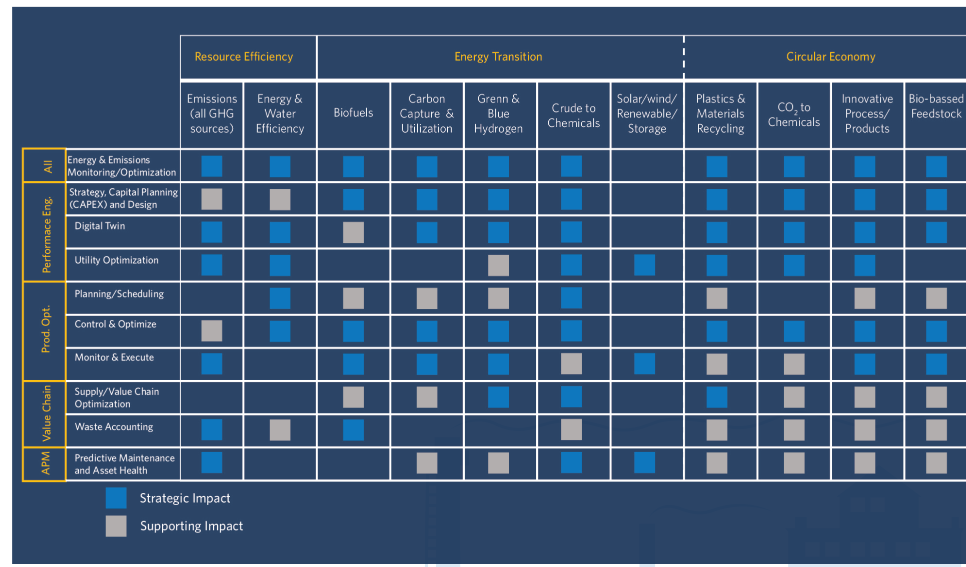

Figure 18. The mapping of digital technology solutions to sustainability initiative areas of focus.

Real-World Customer Examples

Innovators and first movers are employing digital solutions to increase their opportunities to gain competitive advantage from carbon reduction across their assets and enterprise. A few examples are summarized here:

- Abu Dhabi National Oil Company (ADNOC) is using online digital twin models of their largest gas field (Shah field) coupled with dashboards tailored to different management and workforce personas, to comprehensively measure, monitor and thereby reduce energy and water use, CO_2 emissions and fugitive emissions. They have already identified over 1 percent of production that was escaping as fugitive emissions.

- (TCM), a consortium advancing carbon capture, is using a data historian and digital twin models of their carbon capture systems to fully characterize, model and analyze the performance of new carbon capture solvents, membrane technologies and column arrangements, to accelerate carbon capture projects.

- Carbon Capture Inc., a CO_2 direct air capture innovator startup company, is using advanced models and industrial AI to innovate, prove and commercialize its innovative carbon capture and green energy processes.

- CEPSA, a Spanish refiner, is using advanced dynamic optimization solutions to optimize its hydrogen network in the La Rabida refinery, reducing flaring, hydrogen losses, and energy use, and achieving significant CO_2 emissions reduction.

- Air Products, operators of the largest hydrogen network in the US Gulf Coast, is using models of their distributed blue and gray hydrogen production plants to achieve improved operations (reducing energy use and carbon emitted) and to reliably operate the entire network that spans several states from a single technical center.

- Alcoa Australia has deployed online digital twins at the powerhouses serving its West Australia alumina refineries to very significantly improve steam boilder performance, reducing overall energy use and carbon emissions significantly.

These are just a few examples of the opportunities where digital technologies can accelerate progress in industrial carbon emissions reduction.

Summary

Carbon emissions reduction in particular and sustainability in general are a focus for major industry investments over the next five years. The vast majority of asset-intensive companies report that they view progress in carbon emissions reduction as creating competitive advantage. The forces that they see as pushing them to increase the sustainability of their companies are broad, and therefore not likely to be diminished irrespective of regulatory backdrops.

Today, there is no singular approach being taken toward carbon reduction and sustainability. Some areas where innovation is likely to continue to drive change and improved economics are also areas being heavily invested in, such as the end-to-end hydrogen value chain, carbon capture, energy efficiency and bio feedstocks. Moreover, with the heavy emphasis on making rapid progress in sustainability, digital technology is emerging as a fundamental enabler of carbon reduction, energy transition and sustainability.

For more information on how novel software embedding digital solutions can help your company achieve competitive advantage in this time of sustainability imperatives, visit www.aspentech.com.

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About Aspen Technology

Aspen Technology (AspenTech) is a global leader in asset optimization software. Its solutions address complex, industrial environments where it is critical to optimize the asset design, operation and maintenance lifecycle. AspenTech uniquely combines decades of process modeling expertise with artificial intelligence. Its purpose-built software platform automates knowledge work and builds sustainable competitive advantage by delivering high returns over the entire asset lifecycle. As a result, companies in capital-intensive industries can maximize uptime and push the limits of performance, running their assets safer, greener, longer and faster.

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