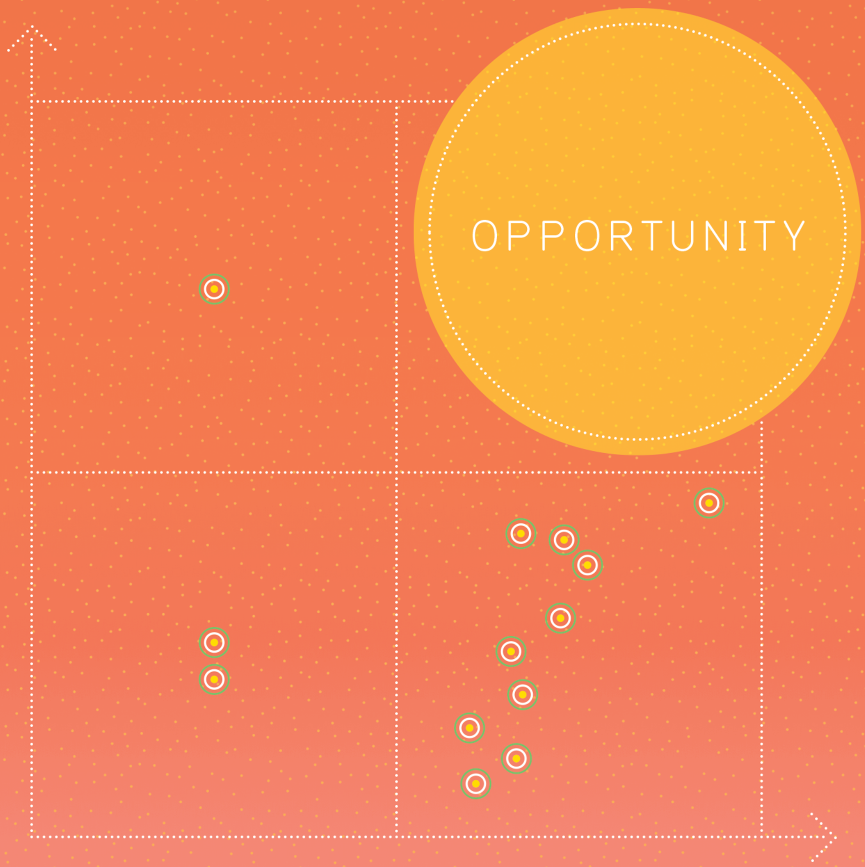
An "Integrated Energy" Test Center

Leveraging Experience to Create a Unique Test Center for Diverse Clean Energy Technologies that Augment Conventional Energy Production



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Introducing the “Integrated Energy” Test Center »

As we often see in the energy industry, the introduction of new technologies can be challenging. Energy producers have a mandate to provide consistently reliable and affordable electricity to their ratepayers. They are understandably cautious when introducing new technologies into scaled production.

Yet the challenge in emerging energy sectors is that demonstrations that would assure producers of new technologies' readiness for scaled deployment often fall short. Laboratory settings can't fully mimic real world-operating conditions in terms of weather, durability, scale, and others. And while single technology demonstrations are helpful when a given technological solution is obvious and preselected, in emerging areas, technological solutions aren't obvious and preferable platforms are unclear. Altogether, producers undertake significant expense and risk to demonstrate a single technology that may or may not be appropriate. Accordingly, we have seen many single-technology demonstrations delayed or canceled, sometimes even before they begin operation.

Energy test centers bypass this dilemma. They allow the side-by-side or sequential comparison of multiple, emerging energy technologies in true operating conditions. They can address "stack risk", which refers to the risk to existing permitting that a power plant assumes in order to test a new technology. Subsequently, they can reduce deployment costs as an initial blanket approach facilitates the testing of multiple approaches. With lower costs of development, they promote experimentation, innovation, and collaboration among participating innovators. Finally, energy test centers can enable cost effective scale-up by taking a more methodical, informed approach to deployment.

Today, several test centers are in operation. In the area of carbon capture, which is a highlighted sector in this publication, the National Carbon Capture Center (NCCC) in Wilsonville, Alabama is a prominent example of an energy test center. At this site, multiple carbon capture technologies and processes are connected to an operational power plant and tested, measured, and refined. It is an invaluable resource, both to the innovators, their prospective customers, as well as to the plant operators.

Also operational are test centers for various wind turbine and motor designs (the National Wind Technology Center and the Marine Energy Test Center), solar heat collecting and focusing technologies (National Solar Thermal Test Facility), solar photovoltaic technologies (SolarTAC), marine based oil cleanup approaches (OHMSETT), and ocean energy generating approaches (the European Marine Energy Centre and the Ocean Energy Test Site). Some test centers pursue multiple sectors, such as broad clean energy technologies (Avista's Clean Energy Test Site and the Renewable Energy Test Center) and a facility that tests everything from oil, to gas, geothermal, and renewable energy technologies (RMOTC).

Each of these test centers isolates a sector then opens the door to multiple approaches within that sector with the aim of gaining insight into what their various performances would be at scale. This benefits the producers, for they are able to gain greater knowledge and insight before selecting any one technology for larger scale testing and deployment. It benefits innovators as well, by lowering barriers to real world testing, benchmarking, and exposure to prospective customers.

Yet lacking in this portfolio of energy test centers is the "integrated energy" test center. We define the "integrated energy test center" as one that includes as many aspects of a selected conventional platform as possible in the category of those to be reexamined and reinvented.

Implicit in the definition of the integrated energy test center is the blending of clean and emerging technologies with conventional technologies. The integrated energy test center is the metamorphosis of existing approaches into new ones that meet producer's and society's needs far into the future. It's the leveraging of potentially brilliant, efficient, and cheaper approaches with our existing, reliable, and valuable energy infrastructure. Unfortunately, at the time of publication, such an integrated energy test center does not exist.

Tri-State Generation and Transmission Association (Tri-State), a cooperative utility outside Denver, CO, is seeking to rectify this situation through the world's first integrated energy test center. This test center is envisioned as adjacent to and integrated with Tri-State's existing 250 MW Escalante Generating Station west of Albuquerque, New Mexico and will facilitate the real-world testing and development of technologies that can augment the performance and compliance of fossil fueled power plants.

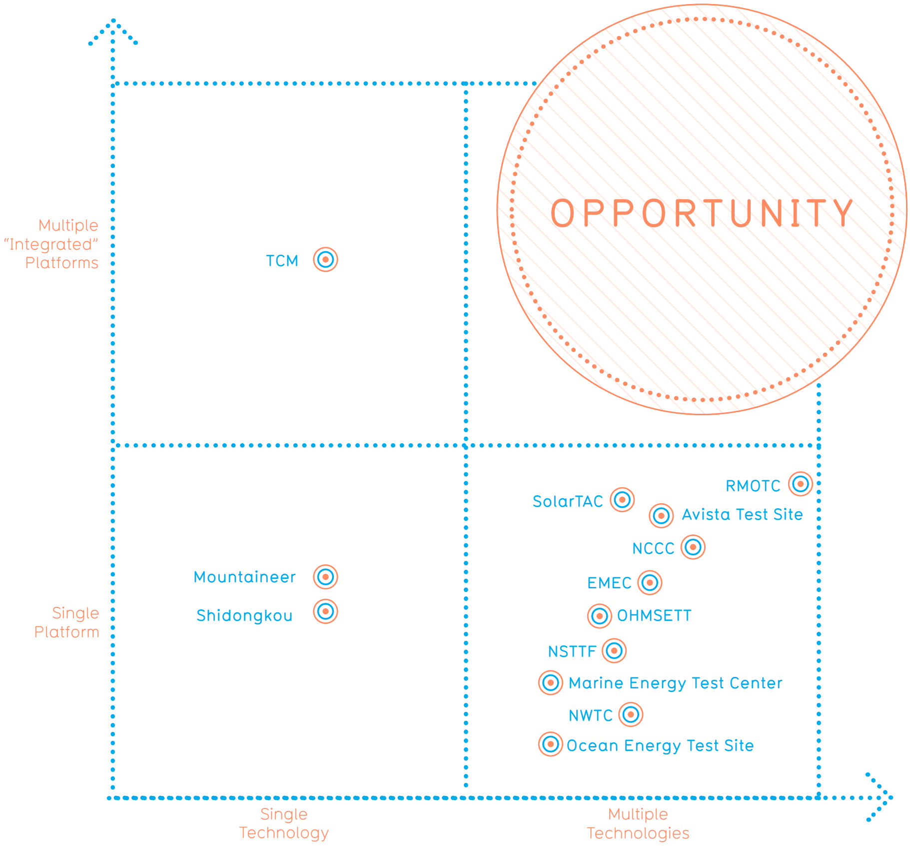
Implicit in the definition of the integrated energy test center is the blending of the clean and emerging technologies with conventional technologies.

The Integrated Energy Test Center is envisioned to be a place where multiple innovators can come and concurrently test their technologies. True to the integrated nature of the center, the Integrated Energy Test Center aims to host new technologies focused on augmenting virtually any and every element of the power plant, from pre-combustion, to combustion, to post combustion research and development. Envisioned testing platforms include coal processing, steam hosting for industrial purposes, heat steam recovery for energy output gains, solar augmentation of the steam cycle, constituent emission detection and removal, and other approaches supplied by equipment manufacturers, to name a few such processes.

The cornerstone of the Integrated Energy Test Center will be the International Carbon Utilization Center (ICUC), the first end-to-end carbon solution accelerator that accelerates the development of unconventional carbon capture technologies as well as the utilization of the captured CO_2 to create value out of what is currently a waste product.

The Integrated Energy Test Center possesses tremendous potential, both for producers and for innovators. Yet to recognize this potential, a greater understanding of past and present single technology deployments and single sector test facilities must first be gained. From there, experience can be leveraged, lessons can be learned, progress can be made, and the value of the Integrated Energy Test Center becomes glaringly apparent.

Energy Test Center Category Matrix



Challenges with Single Technology Deployments »

As mentioned, an emphasized sector in this publication is carbon capture. We narrow our discussion of this sector specifically to post-combustion carbon capture technologies, given that there is an existing power generation infrastructure to address and equip.

In the area of carbon capture, various energy producers and others have deployed single selected technology, pre-commercial demonstrations. The technologies are chosen for various reasons, but often come down to the fact that the technologies' developers are leaders in the sector and had already spent significant time and money to develop the technologies. Such factors reassure energy producers that a deployment has a reasonable chance of success and/or potential to lead to larger scale deployment.

Yet as we see from experience with such deployments, a shortcoming includes the need to preselect only one, single approach from within the entire sector before the technology is proven, either in operational conditions or at the deployed scale. When uncertainty exists, this can lead to significant costs and consequently the delay or cancellation of the entire project, which can be a detriment to the industry as a whole.

Only One Approach

Today, many energy producers are testing new technologies with the goal of meeting cost and performance parameters that have not yet been attained. In these situations, single technology deployments are inherently risky.

For such deployments, energy producers usually have to use incomplete information to make decisions about which technologies to deploy. Models have to be constructed that extrapolate the performance of a given technology from different scales or conditions and apply it to the desired deployment scale and conditions. The success of the deployment depends to a large extent on assumptions built into these models.

This isn't to say that single technology deployments aren't valuable. Tremendous insight and operational knowledge can be gained during these deployments.

It also must be noted that, in many cases, enough is known about the needs of the deployment as well as the capabilities of the technology to reduce or eliminate uncertainty for single technology deployments. For instance, those tied to enhanced oil recovery (EOR) tend to be well understood and, at current oil prices, are acting as a significant driver for the adoption of carbon capture technologies.

We focus our attention instead on those deployments that have the goal of meeting new cost and performance parameters and risk profiles that have not yet been attained. To gain insight into experiences with such technologies, we seek to review single technology deployments that are not tied to EOR (which would connect the project to the economics of oil), capture an arguably meaningful minimum size of 20-megawatts CO_2 equivalent, and are currently operational or have been completed. Furthermore, while all fossil fuels and combustion cycles are of interest, we're biased towards deployments tied to coal (given the heavier carbon footprint and global distribution of coal) and are post-combustion (meaning that they can be retrofitted and address the existing infrastructure, as opposed to design specific).

Delayed or Cancelled

The Carbon Capture and Sequestration (CCS) Technologies Program at the Massachusetts Institute of Technology (MIT) conducts research into technologies to capture, utilize, and store CO_2 from large stationary sources.[1] As part of this program, a comprehensive database of carbon capture projects has been assembled.

Focusing on the segment tied to power plant CCS, we see that out of 48 large-scale and pilot sized CCS projects worldwide, only nine would have met our aforementioned criteria had they all proceeded as planned.

Three of them have been canceled, placed on hold, or are in jeopardy:

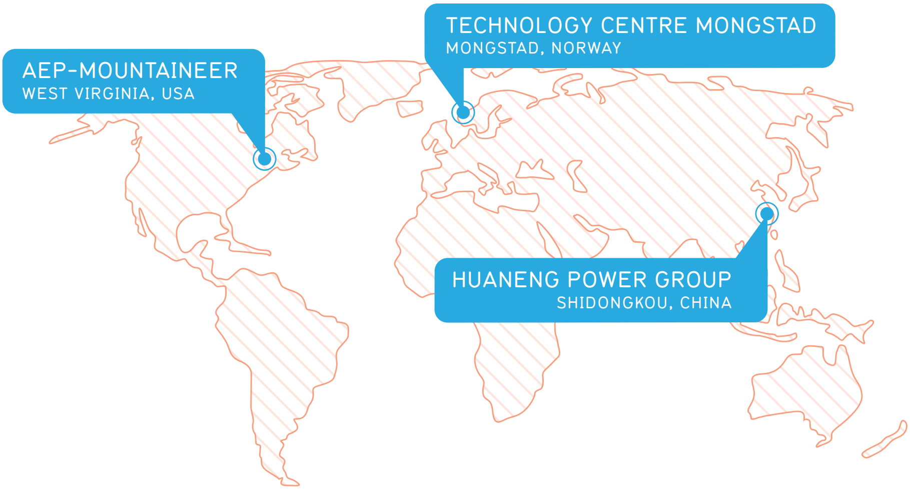
- Scottish Power's Longannet would have been a 330-megawatt post-combustion capture and sequestration project but was cancelled by the Scottish government in October 2011. Instead the £1B was used on other projects.[2]
- ENEL's Porto Tolle would have been a 660-megawatt post-combustion capture and sequestration project from a newly constructed coal power plant, but was placed on hold in May 2011 when Italy's top administrative court annulled the Environmental Ministry's decree approving the project.[3]
- TransAlta's Project Pioneer would have captured and sequestered one million tons of CO_2 per year from a 450-megawatt power plant beginning in 2015 but was cancelled in April 2012 after TransAlta and its partners (Capital Power and Enbridge) backed out of the project, stating that it did not make financial sense.[4]
- PGE's Belchatow is a planned two-phase post-combustion capture and sequestration project, first at 250-megawatts in 2014 and subsequently 858-megawatts in 2015. While the project is still technically in development, in May 2012 PGE announced that it was in no position to start the project and that it needed state support.[5]

Three of them are still in development:

- E.ON's ROAD (Maasvlakte) project in the Netherlands is a new 1-gigawatt power plant coupled with a 250-megawatt slipstream for carbon capture and sequestration. The plant is slated to begin running in 2013, and carbon capture will become active in 2015. The total cost of the project is estimated to be €1.2 billion (US $1.6 billion).[6]
- Turceni Energy's Getica project in Romania will capture CO_2 using either chilled ammonia or an advanced amine process from a 330-megawatt slipstream. The power plant's full output is 2,000-megawatts. The power plant is currently undergoing a retrofitting process, which is due for completion in 2015, at which time the carbon capture facility will be operated.[7]
- Tampa Electric's 250-megawatt Polk Station project in Ruskin, Florida will capture and sequester CO_2 from a 75-megawatt slipstream using Siemens "POSTCAP" technology beginning in 2013 and will reach full operation in 2015. The US DOE awarded this project an $8.9 million grant in July 2010.[8]

Building Upon Case Studies

Only two facilities in the world that are not tied to EOR, capture at least 20-megawatts of CO_2 equivalent, and are currently operational or have been completed: AEP's Mountaineer project in West Virginia and Huaneng Power Group's Shidongkou facility outside Shanghai, China.



American Electric Power (AEP) - Mountaineer
West Virginia, USA

AEP partnered with Alstom, RWE, NETL, and Battelle Memorial Institute to develop and deploy what was to be a two-phase CCS project at its Mountaineer Station in New Haven, West Virginia (see Image 1).

The first (validation) stage was initiated in September 2009 and was scheduled to operate between 18-months and five years. It consisted of diverting 20-megawatts from the coal-based power plant's 1,300-megawatt slipstream to capture carbon post-combustion using Alstom's chilled ammonia technology and subsequently sequester it at 1.5 miles depth in the saline Mount Simon Sandstone.[9]

The validation project came onto operation in October 2009.[10] By December 2010, 21,000 metric tons had been captured at >90 percent capture rate, ~4,400 hours of operation had been completed, and 15,000 metric tons had been stored.[11] Process availability almost reached 100 percent for both capture and storage.[12]

Despite the success of the validation phase and a $334 million DOE award to support half of the total cost of the $668 million, 235 MW phase 2 scale-up, AEP announced the completion of Phase 1 operation and the cancelation of Phase 2 in May 2011.

The project had been driven entirely by regulatory concerns. Yet with the U.S. government's indecision on carbon capture and climate change policy, AEP could not justify the expenses associated with the continued operation of Phase 1 nor the substantial additional construction and operation costs associated with Phase 2.

Image 1

A portion of the Mountaineer Plant carbon capture system project validation facility

Source: American Electric Power

Huaneng Power Group

Shidongkou, China

This government-owned, 1,320-megawatt coal fired facility outside Shanghai, China has received significant attention in recent years, as observers have wondered whether it breaks through longstanding carbon capture cost barriers.[13]

The carbon capture facility captures and makes available for sale 40-megawatts of CO_2 equivalent.[14] The CO_2 sells for commercial use for approximately $12 per ton. The facility broke ground July 2009 and reportedly cost $24 million to build.[15]

Huaneng reports that it costs an unusually low $30–35 to capture and purify (for use in the food and beverage industry) each ton of CO_2.[16] The capture process alone is reportedly only $20 per ton.[17] The Shidongkou retrofit builds on the work of a smaller facility, installed at the Gaobeidian power plant in Beijing in 2008.[18]

Huaneng has not yet revealed all the technical details of its CCS process. Huang Bin, head of Huaneng's Research and Development Division in Beijing, says that the company has made unspecified changes in the design of the plant and the chemistry of the solvent, which increased the energy efficiency of the system by 11–14 percent and reduced the cost of installation by a factor of 10 per ton of CO_2.[19]

Duke Energy has a partnership with Huaneng and has been planning to analyze the cost of installing and running Huaneng's technology at its Gibson Station power plant in Indiana.[20] EmberClear, an energy company based in Calgary, Canada, has licensed a suite of Huaneng's clean-coal technologies, including the capture technology in place in Shanghai, for deployment in the West.[21]

Howard Herzog, a chemical engineer researching carbon sequestration at the Massachusetts Institute of Technology in Cambridge, says a deeper inspection of the Shidongkou facility might reveal that its secret comes down to things such as cheap labor and fewer regulatory burdens.[22] Sarah Forbes, a carbon-sequestration expert at the World Resources Institute, an environmental think tank in Washington DC, says that Huaneng's costs for carbon capture are in proportion with general costs in the Chinese coal industry, which tend to be about one-third of those in the United States.[23]

Image 2

U.S. Energy Secretary Chu visits Shidongkou

Source: China Huaneng Group

Technology Centre Mongstad
Norway

Technology Centre Mongstad (TCM) is not an energy test center. It doesn't allow the entrance and exit of various technologies. Instead, it assumes the conventional approach of preselecting technologies in advance of deployment. Yet it has two interesting characteristics that are worthy of an energy test center: it is testing two separate carbon capture technologies in parallel, and is varying at will the CO_2 concentration in the flue gas, as well as the temperature and pressure, among others.

TCM is the world's largest facility for testing and improving CO_2 capture technologies.[24] It is located at Mongstad near Bergen, on Norway's west coast, and was inaugurated in May 2012. The final cost came in at around $1 billion, 10 times more than had been foreseen.[25]

TCM focuses on testing and improving CO_2 capture technology. Flue gas can come from a refinery next door, or from the gas-fired power station.[26] Flue gas coming from Dong Energy's power station next door contains about 3% CO_2, while the pipe from the cracker at Statoil's Mongstad refinery comes in at around 13%. This means that gas can be delivered to the capture systems with whatever the operators want in terms of CO_2 concentration, temperature and pressure, enabling testing under real-world conditions.[27]

TCM is not only one of the first large scale demonstration plants, but also the first of its kind to test two different types of capture technologies from two different sources of CO_2, side-by-side.[28]

Designed to capture about 100,000 tons per year of CO_2, the project will be the largest demonstration of CO_2 capture technologies to date.[29]

The main ambitions of the Technology Centre are to:[30]

- Test, verify and demonstrate CO_2 capture technology owned and marketed by vendors
- Reduce cost, technical, environmental and financial risks
- Encourage the development of the market for carbon capture technology
- Aim at international development

TCM is a joint venture between Gassnova (on behalf of the Norwegian state), Statoil, Shell and Sasol.[31]

The owners and their shares are:[32]

- Gassnova: 75.12 %
- Statoil: 20.00 %
- Shell: 2.44 %
- Sasol: 2.44 %

TCM DA has its own management, which is responsible for operations and the testing programs. Potential end users of the CO_2 capture technology own TCM. The goal is to bring in additional owners.[33]

TCM's partners have made a clear commitment to technology improvement and invested 5 billion Norwegian kroner for the construction and development of the technology center.[34]

TCM selected two processes, a chilled ammonia process from Alstom and an amine process from Aker Clean Carbon (ACC).[35]

Both technologies are post-combustion capture and utilize a solvent for absorbing the CO_2 from the flue gas. Both are also designed to capture 85% of the CO_2 contained in the flue gas from the refinery cracker and the combined heat and power plant.[36]

Alstom is a large global player in the power generation industry. Providing environmental solutions to customers throughout the world, Alstom continues this with significant efforts in capture technology research and development with a vision to offer CO_2 capture technologies commercially by 2015.[37]

Aker Clean Carbon is a small company in the Aker family that specializes in the development and sale of CO_2 capture technology and complete CO_2 capture facilities. Aker Solutions, the largest member of the Aker family, will play a central role in projects by delivering comprehensive engineering services and facility construction.[38]

Image 3
The TCM facility in Norway

Source: PennEnergy

Advantages of Energy Test Centers »

As mentioned in previous sections, single technology demonstrations afford value to energy producers when a variety of parameters are known. But when parameters such as deployment costs, operational costs, reliability, scalability, and others aren't known, single technology demonstrations can prove less beneficial.

Instead, an energy test center that both concurrently and dynamically serves as host to multiple platforms can provide tremendous value to energy producers, consumers, and service and product vendors who are looking to spur innovation in, gain insight into, and establish a greater degree of confidence that technologies will be able to meet multiple needs as they are scaled up.

Benefits of energy test centers include: the ability to concurrently test and development multiple technologies; the fact that they reflect "real world" operating conditions; the ability to address "stack risk"; a potential to reduce the costs of deployment; the promotion of experimentation, innovation, and collaboration among technology developers; and the ability to enable cost-effective scale up.

Facilitates Concurrent Testing and Development Of Multiple Technologies

Whereas energy producers who embark on single technology demonstrations need to preselect the technology before deployment and more or less lock themselves into the given technology for the life of the demonstration, energy test centers offer a more nimble approach.

An energy test center is simply a hosting center for multiple technologies. While some energy test centers will host technologies for a longer duration than others, they are not permanently wedded to any one technology or approach. Thus, opportunity costs are reduced.

Energy test centers simply provide the platform that would in turn enable a variety of approaches to deploy and demonstrate. Although energy test centers can test technologies sequentially, a design that simply provides a platform for technologies to come and go makes it feasible to deploy and demonstrate multiple technologies at once.

The energy test center permits energy producers to obtain an "apples to apples" comparison of how a variety of technologies perform. After this comparison, producers can make more informed decisions about which technologies to work with, continue to develop, and scale-up.

Energy test centers are ideal for emerging sectors where industry has yet to identify an ideal solution, achieve desired parameters, and gain sufficient insight to make fully informed deployment decisions.

Reflects the Real World

A primary concern among energy producers is the accuracy of performance predictions that have been extrapolated from laboratories and applied to the "real world" – i.e. typical conditions at operational power plants.

In laboratories, environments are controlled. Those testing technologies can select desired temperatures, lighting, and other conditions. They can eliminate external threats, ensure predictability, and avoid the constraints linked to co-operation with existing infrastructure.

Without reliable data and predictions as to how technologies will perform when removed from laboratories' controlled environments, energy producers are left precariously dependent on the accuracy of their and the technology developers' models.

With a modular design, energy test centers can enable technology developers to deploy adjacent to existing infrastructure, and subject these technologies to the same environmental conditions they would experience if they were scaled up and deployed. The same heat, cold, rain, snow, haze, dust, storms, and other conditions that are common in operational conditions would now be applied to the deployed technologies. This in turn enables energy producers to gain a more accurate view of the sector's various technologies and subsequently make better-informed decisions when selecting technologies to further develop and scale up.

Addresses "Stack Risk"

Energy producers must endure a rigorous process to secure permitting for their power plants.

Permitting processes exist around the world. In the United States, most large sources and some smaller sources of air pollution are required to obtain a title V operating permit. This requirement comes from Title V of the Clean Air Act, as amended in 1990. State and local permitting authorities issue most title V permits. These permits are often called part 70 permits because the regulations that establish minimum standards for State permit programs are found in the Code of Federal Regulations at 40 CFR part 70.[39]

Anytime a modification is made to the power plant, including the addition or removal of hardware, which could change the level or quantity of emissions from the power plant's stack, the power plant is at risk of having its permit revoked and thus having to undertake a new laborious, time consuming permitting process.

If an energy producer wishes to test a new technology, it assumes stack risk based on the new technology's profile. It has to ensure that the new technology will meet permitting requirements, or it has to obtain a waiver for the demonstration. If an energy producer wishes to test several technologies, it assumes stack risk for each new technology it deploys. Such a burden makes single technology demonstrations cumbersome.

Energy test centers can reduce this burden. Rather than permitting and assuming stack risk for every new, sequential technology tested, the goal of an energy test center is to permit the approach.

In this case, the center's blueprint would be permitted at the beginning of design, with the specific parameters of what would and what would not be allowed clearly specified. Maximum tolerances for air pollutants – both from the machinery itself as well as those returned to the stack – along with water and other discharges would be identified and permitted.

With clear parameters in place from the center's origination onwards, energy producers are able to rotate technologies in and out as they please, testing as many or as few as they wish, without seeking a new permit for each deployment, as long as those that were allowed to test fulfill the requirements of the blanket permit. To those who wish to test equipment at the facility – and more broadly develop and sell products to energy producers, such an approach would provide clear performance criteria and de facto standards, telegraphing direction to an emerging energy sector.

Reduces Deployment Costs

As previously mentioned, an energy test center's permitting process can be simpler and thus cheaper than for single technology demonstrations. This alone can reduce costs of deployment, especially as numerous technologies are tested.

Yet another large cost benefit in the energy test center platform is inherent in its structure. Ideally, an energy test center would be established in a similar manner as a housing development: the energy producer would establish a plot or plots with standardized connections and amenities by which technology developers would design their equipment to fit and connect.

Thus, energy producers need only finance the construction of the "plots" that would in turn enable the technology developers to deploy. The financing of the technology developers deployment is now separated from the overall equation, and is no longer an upfront cost associated with the facility's construction. Of course, the opportunity exists for developers with unique needs to privately fund design-specific plots that would enable them to specify plot parameters for their own use. But such a course of action or cost isn't necessary by design.

In fact, given the resources afforded by the energy test center (including the permitting, provision of space and resources, etc.), a substantive portion of technology developers may deploy at the facility at their own cost or, even better, while paying rent.

Promotes Experimentation, Innovation, and Collaboration

Energy test centers offer several opportunities for experimentation, innovation, and collaboration.

One of the most obvious comes from the fact that at energy test centers where multiple technologies are concurrently tested, the operators of the new technologies that are being tested are on site at the same time. Furthermore, for those energy test centers focused on a single application, each operator on site will have the same objective.

In such a framework, interactions between the various operators would happen organically. Yet energy producers have the opportunity to further the interactive process by specifically organizing social events, formal events, broader group challenges, or other activities that will induce research collaboration. Such organization is to the energy producers' benefit, for the operators on site are focusing on accomplishing the energy producers' goals.

Collaboration not only happens between technology operators but between the operators and the energy producers (who are managing the facility) as well. Such collaboration can be powerful, as new technology operators feed valuable information and insight into their technologies' performance to the energy producers, which can help energy producers anticipate the needs and requirements of these new technologies as they scale up.

Conversely, the likely more experienced energy producers on site can provide guidance and expertise on power plant operations, needs, conditions, and compatibilities to new technology operators. Together, the technology operators and energy producers gain insight and potentially solve problems, furthering the potential of the technology.

Energy test centers that are established in a way to facilitate easier, standardized access (such as the aforementioned "plots" approach) to reduce the barriers to entry and deployment, thus promoting experimentation. With such an approach, technology developers can move their technologies out of laboratories and into "real world" testing at a faster pace. The fact that the energy producer is less wedded to the deployed technology as it would be under single technology demonstration platforms means that both the technology developer and the energy producer can modify the approach as it happens, making changes and improvements as needed.

Combine the freedom to experiment with the collaborative elements, both of which are uniquely afforded by the energy test center, and the potential for innovation is unparalleled.

Enables Cost-effective Scale-up

Energy test centers can enable a more cost-effective way to develop and scale-up new technologies.

As previously mentioned, inherent in the energy test center "plot" design is reduced up-front capital costs. Yet an energy test center with a "plot" design can offer dramatic cost savings through its scale-up process. This can be illustrated by example.

Let's say hypothetically that an energy producer is seeking to develop post-combustion technologies for fossil fuel power plants. To do so, it diverts 20-megawatts equivalent of slipstream to 10 facility plots, each plot receiving an equal amount of flue gas. Under such a scenario, a technology developer can participate and test at the center with equipment that manages as little as 2-megawatts equivalent.

Yet the plots can also be modularly combined, affording the technology developer and energy producer the ability to test any multiple of 2-megawatts, up to a maximum 20-megawatts. To do so wouldn't require a plant redesign or a test center redesign, nor would it introduce stack risk and the need for a new permit. It would simply require the technology developer to link the slipstreams (and other provisions) from multiple plots together and direct them to its one, larger technology demonstration. Such an amenity is of unprecedented value.

Global Precedent for Energy Test Centers »

With the value afforded by energy test centers, it's no wonder that a number of them exist and are providing enormous value in a variety of sectors.

Below, a variety of test centers are profiled. While not a comprehensive list, these examples illustrate the global precedent for energy test centers. Our specific interest in carbon leads us to separate and highlight carbon capture test centers above the rest.

Yet examples of energy test centers focused on wind, solar thermal, solar photovoltaic, conventional energies, water pollution, ocean energies, and diverse clean energies demonstrate the variety of applications upon which energy test centers have been applied and are providing value.

For Carbon Capture

The need for breakthroughs in the area of carbon capture is obvious to energy producers and others who work in the industry. A 2012 Prize Capital publication highlights the challenges associated with conventional carbon capture technologies:[40]

Given that, on a mass basis, CO_2 is the 19th largest commodity chemical in the United States, CO_2 is routinely separated and captured as a by-product from industrial processes, which include synthetic ammonia production, H_2 production, and limestone calcination.[41]

Conventional post-combustion carbon capture processes implemented at power plants have simply scaled up these smaller scaled processes. The dominant methods of carbon capture include the use of bases: amine solvents and chilled ammonia. These technologies are not cost-effective when considered in the context of sequestering CO_2 from power plants.[42]

Unlike previous industrial applications, most power plants and other large point sources use air-fired combustors, a process that exhausts CO_2 diluted with nitrogen. Flue gas from coal-based power plants contains 10-12 percent CO_2 by volume.[43] For effective processing, the CO_2 in these exhaust gases must be separated and concentrated and the solvent must be regenerated.

These processes currently consume a tremendous amount of energy. A common estimate is that the energy required per MWh would rise 36% for a typical post-combustion plant retrofit.[44]

Accordingly, the cost of CO_2 capture using current technology is on the order of $150 per ton of carbon.[45] Analysis indicates that adding existing technologies for CO_2 capture to an electricity generation process could increase the cost of electricity by 2.5 cents to 4 cents/kWh depending on the type of process.[46]

Furthermore, the conventional carbon capture technologies are water intensive. Cooling the amines for CO_2 absorption, which generates heat, leads to an additional load on the cooling tower, causing more water to be lost.[47] Compressing the CO_2 to the supercritical conditions needed for storage requires cooling, too.[48] Thus, conventional technologies increase water requirements at a given plant by 33%.[49] If the energy lost in the carbon capture process is accounted for by adding additional capacity, then water consumption would increase by 80 percent.[50]

Finally, there is a general lack of experience with current carbon capture systems at the appropriate scale at power plants. Currently operating CO_2 capture systems in coal-based power plant applications (i.e. amine and chilled ammonia solvent systems) process about 75,000 to 300,000 tons of CO_2 per year. By comparison, a single 550-megawatt (MW) net output coal- fired power plant capturing 90 percent of the emitted CO_2 will need to separate approximately 5 million tons of CO_2 per year.[51]

Thus, given the value afforded by energy test centers, it's no surprise that a test center has been established to focus on carbon capture challenges.

National Carbon Capture Center (NCCC)

Wilsonville, Alabama

In cooperation with Southern Company Services, the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) established the National Carbon Capture Center (NCCC) at the Power Systems Development Facility (PSDF) in Wilsonville, Alabama. The center focuses on developing cost-effective technologies to capture the CO_2 produced by fossil-fueled power plants.[52]

The PSDF was launched in late 1990 with the signing of an agreement between DOE and Southern Company Services. Since completion of the facility in 1996, it has been a center of national efforts to develop coal-based power generation technologies that are reliable, environmentally acceptable, and cost effective.[53]

The PSDF seeks to be large enough to provide commercially relevant data, yet small enough to be cost-effective and adaptable to testing a variety of emerging technology developments. The facility is a test-bed capable of evaluating advanced technologies at multiple scales, with the intent that it allows results to be scaled directly to commercial application.[54]

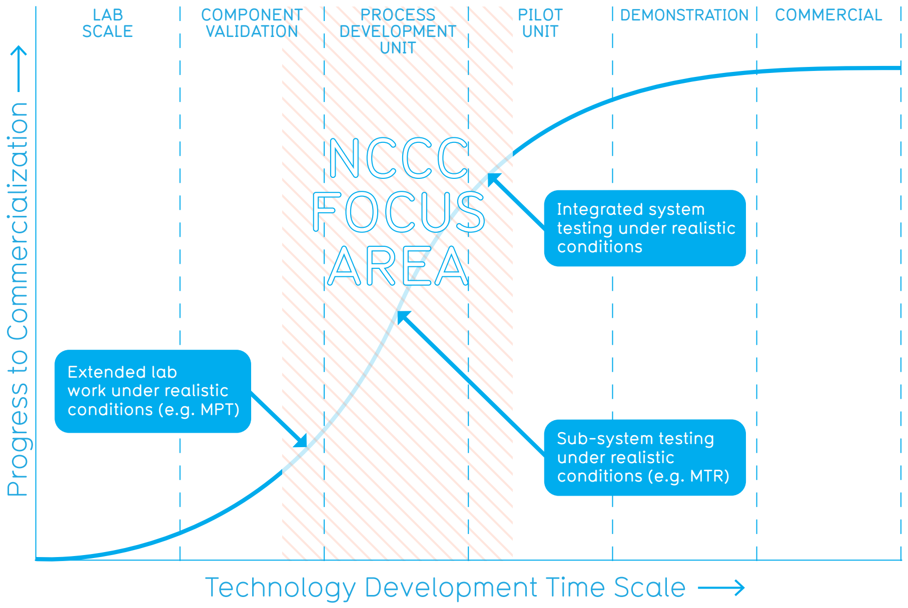
Many of the technologies developed at the facility are now commercially available or are ready for commercialization, including a design for an integrated gasification combined cycle power plant to be built in Kemper County, Mississippi, that will showcase a transport gasifier technology that was developed at the PSDF.

Building upon the successes, the PSDF became home to the NCCC with a focus on carbon capture. The NCCC concentrates on developing cost-effective, commercially viable carbon capture technology for coal-fueled power plants through scale-up and continued technology development by DOE and/or third party technology developers. The NCCC seeks to provide all the necessary infrastructure into which developer's technology can be inserted, allowing developers to provide their technology (equipment or solvent) for testing and requiring developers to pay for out-of-the-ordinary analyses.[55]

The NCCC began operation in October 2008 and is scheduled to continue through September 2013. DOE/NETL and Southern Company Services entered into a five-year cooperative agreement to establish and manage the NCCC. Aside from the DOE and Southern Company, partners in the project include Arch Coal, Electric Power Research Institute Luminant, NRG Energy, Peabody Energy, and Rio Tinto.[56] Southern Company and its partners provided approximately $50 million, while the DOE provided over $200 million, to establish the NCCC and fund it during its project period. During this timeframe, the NCCC and supporting industrial participants' goals include:[57]

- The NCCC will become a cornerstone for U.S. leadership in advanced CO_2 capture technology development.
- The NCCC will demonstrate integrated coal-based energy technology for plants that offer clean coal technology, including carbon capture.
- Technologies developed at the NCCC will be scaled directly to commercial- sized equipment and integrated with commercial projects, including those under DOE's Clean Coal Power Initiative.
- The NCCC will lead the way to lower-cost CO_2 capture technologies and enable affordable, reliable, and clean coal-based power generation for years to come.

Figure 1
NCCC Focus Area



Source: National Energy Technology Laboratory

The NCCC collaborates with technology developers to accelerate their CO_2 capture technology development for application to coal-fueled power plants. The NCCC offers a flexible test center that provides commercially representative flue gas and syngas, and the necessary infrastructure in which developers' technologies are installed and tested to generate data for performance verification under industrially realistic operating conditions.[58]

Testing and developing new CO_2 capture technologies in commercially representative conditions is critical before the technologies can be deployed at full scale. The NCCC seeks to provide such a setting by delivering coal-derived flue gas and syngas over a wide range of process conditions. The NCCC provides the necessary personnel, materials, and facilities needed to conduct this research.[59]

The applied Research and Development (R&D) carried out at the NCCC on components or small pilot- scale systems can help bridge the gaps between fundamental R&D and large-scale commercial demonstration and provides for a seamless transition for promising technologies to migrate from laboratory to commercial applications.[60]

Specific NCCC activities include:[61]

- Test, evaluate, and develop emerging CO_2 capture systems for fossil-fueled power plants. The NCCC includes multiple slip-stream capabilities of variable throughput to accommodate the evaluation of a wide-range of capture technologies, including evaluation of pre-combustion CO_2 capture, post-combustion CO_2 capture, and oxy-combustion processes.

- Test and develop CO_2 capture technologies that provide improved efficiency and cost effectiveness over those currently deemed commercially available. In addition to individual component testing, components of the CO_2 capture process are integrated and optimized to provide data needed for scale-up.

- Test, develop, and optimize components to enable the deployment of carbon capture with minimal increase in the cost of electricity. These components include gas contaminant cleanup, gas separations, coal/biomass gasification or combustion technologies, fuel cell technology, materials, sensor technology, and others.

- Test and evaluate the transport gasifier with CO_2 capture using a variety of fuels including coal/biomass mixtures to characterize the performance of the different technology units, their integration, and balance-of-plant processes.

Technology development at the NCCC includes both pre- and post-combustion CO_2 capture. The pre-combustion CO_2 capture component is located at the PSDF. The post-combustion component is developed at the adjacent Plant Gaston, an Alabama Power coal-fueled generating plant adjacent to the PSDF.[62]

Pre-combustion Carbon Capture

The PSDF became host to the pre-combustion activities at the NCCC. The NCCC is investigating key processes to advance pre-combustion CO_2 capture. These key processes include:[63]

- Gas/liquid contacting systems
- Solvents for CO_2 capture/separation
- Water-gas shift catalysts, reactors, and processes
- CO_2 compression
- Emerging syngas processes (sorbents and membranes)

The NCCC pre-combustion CO_2 test center includes slipstreams with a range of gas flow rates and process conditions using coal-derived syngas for verification and scale-up of fundamental research and development CO_2 capture projects.[64]

The NCCC has the capability to test these systems using a wide range of fuels, including biomass and bituminous, subbituminous, and lignite coals. NCCC staff work closely with DOE and with technology vendors to design individual test systems.[65]

As concepts proceed past the bench scale, testing under industrial conditions with real syngas will provide meaningful pathways to commercialization.[66]

Image 4

The NCCC Gasifier at the Power Systems Development Facility in Wilsonville, AL

Source: Pittsburgh Supercomputing Center

Post-combustion Carbon Capture (PC4)

Much of the NCCC's research will focus on post-combustion CO_2 capture to evaluate new technologies for integration with the existing fleet of pulverized coal power plants.[67]

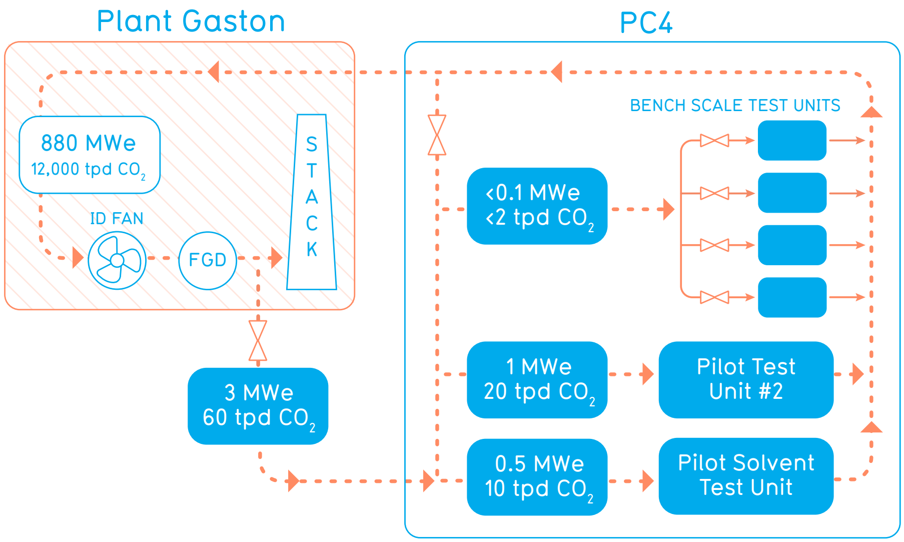
As part of the NCCC, the Post-Combustion Carbon Capture Center (PC4) was installed at the Alabama Power Gaston power plant Unit 5, a 880 MW supercritical pulverized coal unit. The primary purpose of this slipstream test center is to support development of multiple post-combustion CO_2 capture technologies at several scales. The PC4 can:[68]

- Test new solvents and gas/liquid contacting systems
- Regenerate solvents at high pressure
- Evaluate emerging technologies such as sorbents and membranes
- Reduce capex and opex penalties associated with the addition of CO_2 capture

PC4 provides several parallel paths in order to test candidate processes at appropriate scales. It supports integration of test skids developed by others and includes a solvent test unit, an advanced contactor slipstream, and a slipstream for multiple, small-scale tests.[69]

PC4 work is focused on solvents, sorbents, membranes, oxy-combustion, compression.[70] Some of those who are testing at the PC4 include Aker, B&W, MTR Membrane, and Codexis.[71]

Figure 2
Diagram of the Post-Combustion Carbon Capture Center Test Center

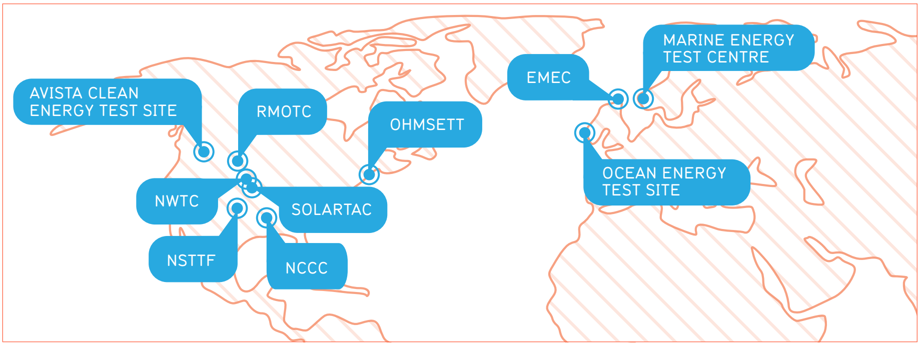


Source: National Carbon Capture Center

For Diverse Energy Technologies

The NCCC is a clear example of the energy test center platform. Yet it's not the only example worth mentioning.

As previously mentioned, energy test centers have established precedent across a spectrum of energy technologies, in various countries around the world. What follows is a representation of this precedent, with examples exhibiting some or all of the characteristics associated with energy test centers.



National Wind Technology Center (NWTC)
Boulder, Colorado

The National Renewable Energy Laboratory's (NREL's) National Wind Technology Center (NWTC), located at the base of the foothills just south of Boulder, Colorado, considers itself the nation's premier wind energy technology research facility.[72]

Built in 1993, the center provides an ideal environment for the development of advanced wind energy technologies. The goal of the research conducted at the center is to help industry reduce the cost of energy so that wind can compete with traditional energy sources, providing a clean, renewable alternative for our nation's energy needs.[73]

Activities at the NWTC are organized under two main categories: Development, and Testing and Operations.

The goal of the wind turbine research conducted at NREL is to assist U.S. industry in developing cost-effective, high performance wind turbine technology that will compete in global energy markets. To that end, NREL researchers work closely with industry partners to research, design, build, test, and refine advanced wind turbine designs. Industry partners are selected through competitive solicitations and share in the costs of research and development (R&D) projects.[74]

In addition to developing the technologies, NREL's researchers conduct utility grid integration research and work to facilitate the adoption of equitable grid access and operational rules for wind in all major regional wind markets.[75]

Testing and operations include a wide range of testing services and activities that address both the technical and the many nontechnical barriers to the use of wind energy systems. While the NWTC facilities enable researchers and industry partners to conduct a wide range of system, component, and field tests to identify and resolve technical design issues, NREL's Wind Powering America team, also based at the NWTC, works with industry stakeholders to remove nontechnical barriers to wind turbine deployment.[76]

The NWTC's facilities offer research and analysis of wind turbine components and prototypes rated from 400 watts to 3 megawatts. Facilities are contained within a 305-acre area that comprises field test sites, test laboratories, industrial high-bay work areas, machine shops, electronics and instrumentation laboratories, and office areas. In addition, there are hundreds of test articles and supporting components such as turbines, meteorological towers, custom test apparatus, test sheds, storage areas, and calibration and measurement instruments. The NWTC also has data acquisition systems, load frames, computers and electronics, machine tools, supporting heavy equipment, and associated required infrastructure including electrical power, water, fire protection, and fiber optic communications.[77]

Engineers provide wind industry manufacturers, developers, and operators with turbine and component testing that ensures performance and reliability. Prototype testing is especially important to capture manufacturing flaws. The NWTC staff conducts tests on components in laboratory environments and on turbines in the field to produce data that can be used to certify and validate turbine designs. Evolving over more than thirty years, with the support of the U.S. Department of Energy, the NWTC has developed test equipment, methods, and data acquisition to foster wind technology testing.[78]

The NWTC offers capabilities in structural testing, drivetrain testing, and field-testing. The capabilities are supported by world-class testing facilities.[79] Furthermore, the Wind Technology Testing Center (WTTC) is a satellite facility that offers U.S. manufacturers a facility to test new blade designs. Both the NWTC and the WTTC offer a full suite of certification tests for turbine blades. The NWTC tests blades up to 50 meters in length while the WTTC can test blades up to 90 meters. With 30 years of blade testing experience, the National Wind Technology Center (NWTC) functions as an expert partner with the newly commissioned WTTC.[80]

Image 5

The National Wind Technology Center

Source: Dennis Schroeder

National Solar Thermal Test Facility (NSTTF)
Albuquerque, New Mexico

Operated by Sandia National Laboratories for the U.S. Department of Energy (DOE), the National Solar Thermal Test Facility (NSTTF) is located on 117 acres on Kirtland Air Force Base in Albuquerque, New Mexico. It was built in 1976 at an initial cost of $120 million. The facility affords prototype and systems testing for concentrated solar power, including for trough, tower, and dish/engine systems.[86]

The NSTTF's primary goal is to provide experimental engineering data for the design, construction, and operation of unique components and systems in proposed solar thermal electrical plants planned for large-scale power generation.[87]

In addition, the site was built and instrumented to provide test facilities for a variety of solar and non-solar applications. The facility can provide: [88]

- High heat flux and temperatures for materials testing or aerodynamic heating simulation;
- Large fields of optics for astronomical observations or satellite calibrations;
- A solar furnace;
- A rotating platform for parabolic trough evaluation.

Specific site features include: [89]

- An eight acre heliostat field and power tower (5 MWth);
- A molten-salt test loop;
- A rotating platform for solar;
- Thermal and optical testing of trough concentrators;
- A16 kilowatt solar furnace for materials, small component, thermo-chemistry and hydrogen generation experiments;
- A dish engine test facility;
- An engine test facility;
- Associated laboratories;
- Specialized test equipment, shop facilities, vehicles, administrative and office buildings.

Image 6
The National Solar Thermal Test Facility

Source: Sandia National Laboratory

Solar Technology Acceleration Center (SolarTAC)
Aurora, Colorado

The Solar Technology Acceleration Center (SolarTAC) is a test center where the solar industry can research, test, validate, and demonstrate solar technologies.[90]

SolarTAC's mission is to increase the efficiency of solar energy products and rapidly deploy them to the commercial market.[91] It was launched in June 2011.

Located near Denver International Airport in Aurora, Colorado, the 74-acre SolarTAC site offers flat, graded topography and excellent insolation conditions with over 300 days of sunshine a year in one of the most progressive renewable energy states in the country.[92]

The SolarTAC site will include facilities for testing both photovoltaic and concentrated solar power (CSP) technologies, including access to the grid.[93] Today the site is nearly full with solar technologies and research from a membership comprised of energy giants such as Xcel Energy; Abengoa Solar; SunEdison; The Alliance for Sustainable Energy, LLC; Amonix; and the Electric Power Research Institute (EPRI).[94]

SolarTAC is Managed and operated by MRIGlobal, a not-for-profit contract research organization headquartered in Kansas City. Founded in 1944, MRIGlobal is one of the nation's leading research institutes, conducting programs in the areas of energy, national security and defense, life sciences, agriculture and food safety, and transportation. In addition to operating its own laboratories, MRIGlobal manages and operates laboratories for the U.S. Department of Energy (DOE) and the U.S. Department of Defense (DoD).[95]

Image 7
SolarTAC Photovoltaic Panels

Source: Department of Energy

Rocky Mountain Oilfield Testing Center (RMOTC)
Casper, Wyoming

RMOTC is an energy test center with unique capabilities, partnering with industry and academia to field-test a broad range of products and processes in a real-world environment.[96]

As a DOE facility, RMOTC has no vested interest in any specific technology. It supports the energy industry by testing new ideas specific to drilling, oil & gas production, flow assurance, geothermal systems, renewable and alternative energies, carbon management, environmental impact mitigation, and more.[97]

RMOTC supports the goals of the National Energy Policy, the Office of Fossil Energy, and the U.S. Department of Energy. The Interstate Oil & Gas Compact Commission (IOGCC), the Independent Petroleum Association of America, the National Stripper Well Association, and the Rocky Mountain Oil & Gas Association are among those that support the unique capabilities offered by RMOTC to industry, government, and academia.[98]

Located on a 10,000-acre U.S. Department of Energy site within Naval Petroleum Reserve No. 3 (NPR-3), RMOTC provides infrastructure and expertise to validate new technology for its test partners.[99] RMOTC provides a neutral, real-world test environment to support the development of innovative technologies specific to the energy industry. Partners can validate their products and processes in a controlled production setting, receive unbiased feedback, and keep proprietary information confidential.[100]

RMOTC's technical and support staff works with its partners to:

- Design a project plan, outlining the most effective means to satisfy test requirements;
- Detail the project scope, schedule, and cost for approval;
- Execute the test and collect pertinent data;
- Deliver a results summary detailing the technology's capabilities.

Image 8
Viewing the RMOTC's geothermal unit

Source: RMOTC

National Oil Spill Response Research & Renewable Energy Test Facility (OHMSETT)

Leonardo, New Jersey

The National Oil Spill Response Research & Renewable Energy Test Facility goes by the acronym OHMSETT, which stands for the "Oil and Hazardous Materials Simulated Environmental Test Tank," the facility's original name. The facility provides independent and objective performance testing of full-scale oil spill response equipment and marine renewable energy systems (wave energy conversion devices), and improving technologies through research and development.[101]

It is the largest outdoor saltwater wave/tow tank facility in North America and is the only facility where full-scale oil spill response equipment testing, research, and training can be conducted in a marine environment with oil under controlled environmental conditions (waves and oil types). With recent emphasis on developing renewable energy sources, OHMSETT's mission has expanded to offer a research and testing venue for wave energy conversion devices.[102]

OHMSETT was established in 1974. It is maintained and operated by the U.S. Department of Interior's Bureau of Safety and Environmental Enforcement (BSEE) through a contract with MAR, Incorporated of Rockville, Maryland.[103] It is located at the Naval Weapons Station Earle Waterfront in Leonardo, New Jersey (approximately one hour south of New York City).[104]

OHMSETT's above ground concrete test tank is one of the largest of its kind, measuring 203 meters long by 20 meters wide by 3.4 meters deep. The tank is filled with 2.6 million gallons of crystal clear saltwater.[105]

The OHMSETT test tank allows testing of full-scale equipment. The tank's wave generator creates realistic sea environments, while state-of-the-art data collection and video systems record test results. The facility has proven to be ideal for testing equipment, evaluating acquisition options, and validating research findings.[106]

Government agencies, academia, public and private companies are invited to contract the use of OHMSETT as a research center to test oil spill containment/cleanup equipment and techniques, to test new designs in response equipment, and to conduct training with actual oil spill response technologies.[107]

Specific features and capabilities include:[108]

- A main towing bridge capable of towing test equipment at speeds up to 6.5 knots
- An auxiliary bridge oil recovery system to quantify skimmer recovery rates
- A wave generator capable of simulating regular waves up to one meter in height, as well as a simulated harbor chop, FM Slides with selectable: slue rates, start and stop
- Pierson-Moskowitz & JONSWAP spectra parameterized by wind speed & scale
- A movable, wave-damping artificial beach
- An oil distribution and recovery system that can handle heavy, viscous oils and emulsions
- A control tower with a fully-computerized 32-channel data collection system as well as above-and below-water video
- A centrifuge system to recover and recycle test oil
- Blending tanks with a water and oil distribution system to produce custom oil/water emulsions for testing
- A filtration and oil/water separator system
- An electrolytic chlorinator to control biological activity
- Permanent and mobile storage tanks that can hold over 227,000 liters of test fluids
- A vacuum bridge to clean the bottom of the tank
- Staging and shop area for special fabrication
- On-site Chemistry Laboratory
- 15,000 lb. forklift

Through a variety of mechanical, electrical, and chemical systems at OHMSETT, the following test parameters can be controlled or measured:[109]

- Sea state (wave height, length, and period)
- Tow speed
- Meteorological data
- Water temperature and salinity
- Volume of oil encountered and recovered by test equipment or protocol
- Oil-water ratios
- Physical characteristics of experimental oil
- Behavior of treated oils

In 2011, The X PRIZE Foundation hosted its Wendy Schmidt Oil Cleanup X CHALLENGE at OHMSETT. The competition is designed to inspire entrepreneurs, engineers, and scientists worldwide to develop innovative, rapidly deployable, and highly efficient methods of capturing crude oil from the ocean surface. The Wendy Schmidt Oil Cleanup X CHALLENGE was launched in July 2010 in the wake of the Deepwater Horizon Oil Spill in the Gulf of Mexico.[110]

Given OHMSETT's ability to deploy and retract a wide variety of technologies, it was the ideal host of this X CHALLENGE. The X CHALLENGE's finalist teams advanced to the competition's Phase II Field Testing, where they demonstrated their ability to efficiently and rapidly clean up oil on the ocean surface at OHMSETT. These technology demonstrations determined the competition's winners.[111]

Image 9

Oil cleanup machine testing at OHMSETT, as part of the Wendy Schmidt Oil Cleanup X CHALLENGE

Source: MSNBC

European Marine Energy Centre (EMEC)

Orkney, Scotland

Established in 2003, The European Marine Energy Centre (EMEC) Ltd is the first and only center of its kind in the world to provide developers of both wave and tidal energy converters – technologies that generate electricity by harnessing the power of waves and tidal streams – with purpose-built, accredited testing facilities.[112]

The Orkneys in northern Scotland serve as the base for the EMEC because of its excellent oceanic wave regime, strong tidal currents, grid connection, sheltered harbor facilities and the renewable, maritime and environmental expertise that exists within the local community.[113]

The EMEC has 14 full-scale test berths. It claims that there have been more grid-connected marine energy converters deployed at EMEC than any other single site in the world, with developers attracted from around the globe. These developers use the facilities to prove what is achievable in some of the harshest marine environments, while in close proximity to sheltered waters and harbors.[114]

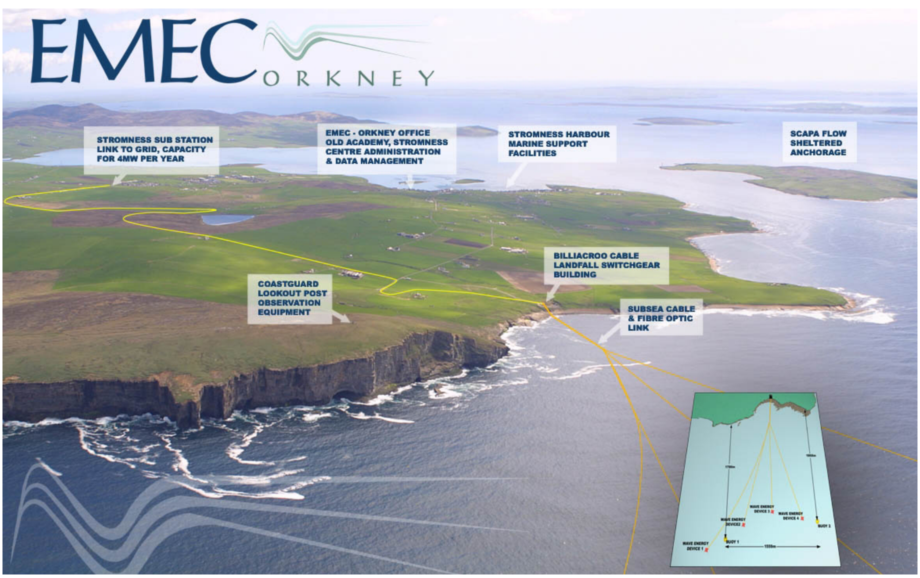
The EMEC also operates two nursery test sites where smaller scale devices, or those at an earlier stage in their development, can gain real sea experience in less challenging conditions than those experienced at the full-scale wave and tidal test sites.[115]

Beyond device testing, the EMEC provides independently verified performance assessments, a wide range of consultancy and research services, and are working closely with Marine Scotland to streamline the consenting process.[116]

The EMEC has coordinated the development of a suite of 12 industry guidelines, six of which are being progressed for global adoption as the first international standards for marine energy.[117]

Image 10

EMEC map displays grid connection and routing



Source: Maritime Journal

Ocean Energy Test Site
Galway Bay, Ireland

The Marine Institute, in association with Sustainable Energy Authority Ireland, established an Ocean Energy Test Site for scaled prototypes of wave energy devices in Galway Bay, Ireland. The Department of Communications, Marine and Natural Resources issued a foreshore lease for the site in March 2006.[118]

The Test Site is situated on the North side of Galway Bay, one mile East of Spiddal. To avoid conflict with shipping, navigation markers on four corners mark it. The site is 37 Hectares in area and is in 21-24 meters of water.[119]

Real time wave information is available for the Galway Bay Test Site. The Marine Institute has installed a Directional waverider at the test site to support developers of Ocean Energy devices. The wave data is updated every three minutes and can be viewed at the through the map on the Integrated Marine Observation System.[120]

A wave climate recording and modeling program, carried out by the Marine Institute in 2004, indicated the suitability of the site for testing of $^1/_3$ - $^1/_5$ scale devices. This facility was designed to provide testing facilities for large-scale prototypes to fulfill the requirements of phase 3 (Process Model) of the Development and Evaluation Protocol for Ocean Energy Devices.[121]

The Galway Bay Test Site is available to all developers of wave energy devices, who have a prototype that is built for open water testing in a relatively sheltered location.[122]

Image 11

Wavebob Ltd. was the first company to use the Ocean Energy Test Site. The company began testing in 2006.

Source: IBM

Avista's Clean Energy Test Site
Rathdrum, Idaho

The Avista Clean Energy Test Site is located in Rathdrum, Idaho. At the site, developers of renewable energy technologies, such as advanced solar equipment, can test, demonstrate, and deploy new technologies under real world utility conditions.[123]

Avista, a Spokane, Washington based electric and natural gas utility company, created the Clean Energy Test Site to allow for deployment and testing of emerging renewable energy technologies. Ultimately the applications could provide additional renewable energy for utility customers.[124]

Marine Energy Test Centre
Rogaland County, Norway

Marine Energy Test Centre AS operates a test center for marine renewable energy with emphasis on floating offshore wind installations. The test center is co-located with Hywind and cooperates with Statoil regarding infrastructure.[81]

The test center provides infrastructure, licenses and services for the testing of floating offshore wind installations. The test center is located in Karmøy in the Rogaland County in Norway.[82]

It is the METCentre's goal to become the preferred international test center for floating off shore wind technology. Moreover MetCentre aims to facilitate increased research into marine energy.[83]

The test center offers:[84]

- Grid connection via sea cable
- Concession assistance
- Access to wind and wave data
- Operation and maintenance assistance
- Work base and warehouse facilities
- Collaboration with research institutes and universities

Enova and METCentre have signed a collaborative agreement whose purpose is to facilitate an increase in technological development within marine energy production in Norway.[85]

Needed: An "Integrated Energy" Test Center »

The energy test centers discussed in this publication demonstrate the broad array of centers in existence. At first glance, one would think that tremendous diversity exists.

The Mountaineer and Shidongkou single technology demonstration facilities each offer (or "offered") tremendous insight into pre-commercial scale operation within a single energy platform of a preselected, single technology. Technology Centre Mongstad (TCM) applies a single, preselected technology to multiple "integrated" platforms by affording more variables for conventional power experimentation.

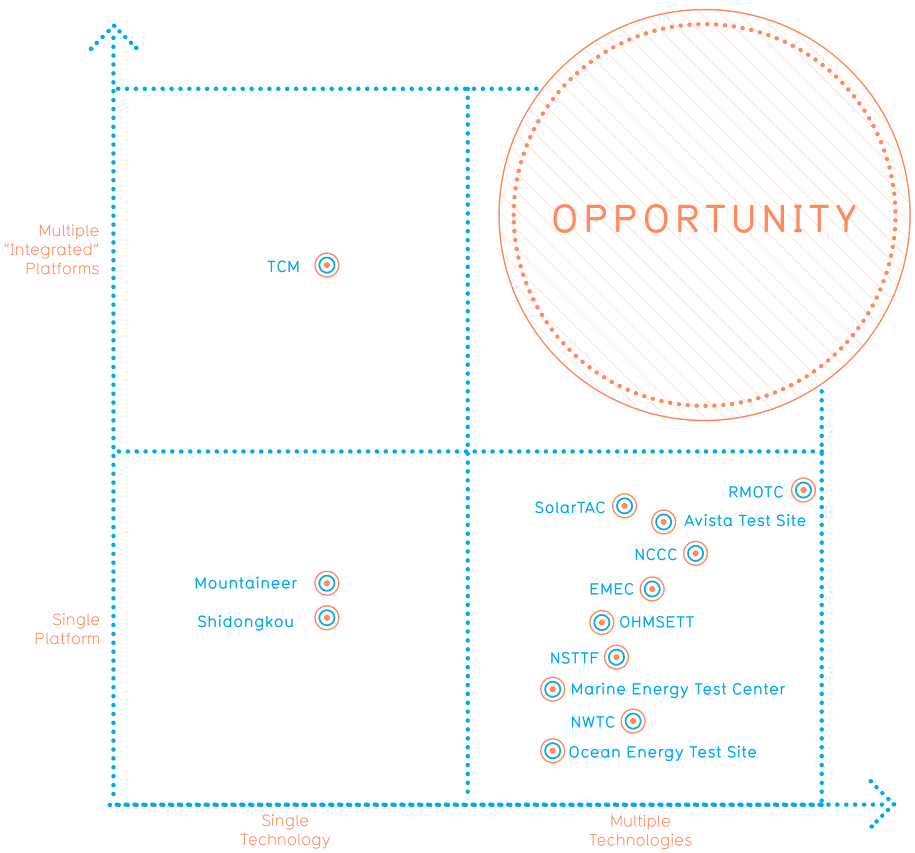
The true energy test centers offer experimentation on multiple technologies. At basic levels, the Ocean Energy Test Site, National Wind Technology Center (NWTC), Marine Energy Test Centre, and National Solar Thermal Test Facility (NSTTF), National Oil Spill Response Research & Renewable Energy Test Facility (OHMSETT), and European Marine Energy Centre (EMEC) are centers that facilitate the testing of multiple technologies, yet within a single energy platform. While technically in the same category, the National Carbon Capture Center (NCCC), Avista Clean Energy Test Site, and especially SolarTAC afford greater diversity of technologies and experimentation.

Almost in a class of its own is the Rocky Mountain Oilfield Testing Center (RMOTC). This facility affords the testing of multiple technologies across multiple energy platforms. Yet these platforms aren't integrated. As previously discussed, we defined integrated platforms to be those that include as many aspects of a selected conventional platform as possible in the category of those to be reexamined and reinvented, in essence combining existing technologies and infrastructure with new ones to create interlinked, hybridized approaches. While the RMOTC affords great ability to demonstrate and experiment, it does not offer the level of reinvention and serial integration between technologies to justify being termed an "integrated energy" test center.

Category Matrix Indicates An Unmet Need

By plotting the aforementioned parameters and characteristics, a matrix can be created that displays the similarities and differences among the reviewed energy test centers. Doing this also reveals one, very large unmet need and opportunity for the creation of an "integrated energy" test center that would afford not only the ability to test multiple technologies, but to do so across a spectrum of integrated energy platforms:

Energy Test Center Category Matrix



Filling the Void: The Escalante "Integrated Energy" Test Center »

Tri-State Generation and Transmission Association (Tri-State) is a consumer-owned, not-for-profit wholesale power supplier serving 44 electric cooperatives in four western states who has recognized and is seeking to fill the test center void through the creation of the world's first integrated energy test center.

The value proposition for the Integrated Energy Test Center is straightforward: Many of the future needs of the electric industry are being developed primarily in laboratory settings, which could be significantly advanced through research and testing at an operating coal-fired electric plant.

Of specific concern is accelerating technological development to mitigate CO_2 emissions by breaking down cost barriers and catalyzing the utilization (rather than sequestration) of the carbon to produce products (such as fuel). This small but growing industry already has over 130 entities developing what each hopes will be game-changing processes.

Unfortunately, laboratory conditions don't mimic the real world, where large-scale energy providers are charted with the responsibility to provide consistent, affordable electricity to their customers. Innovators find it difficult to test their technologies in the real world because of utilities' "stack risk" – the legal, permitting, operational, and cost burdens encountered by a utility seeking to test one single technology.

By focusing on retrofitable technologies and facilitating a smart, diverse selection of platform deployment and testing resources, Tri-State has established a powerful vision for leveraging innovation and progress to support keeping electricity affordable.

Focus on Retrofitable Technologies

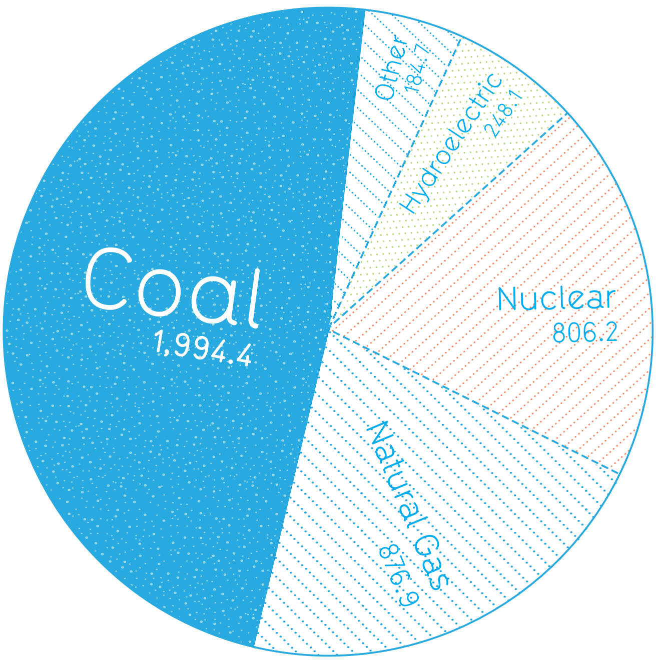
Given that an integrated energy test center seeks to create "hybrid" plants that are a blend of old and new, the focus of the center will naturally be on retrofitable technologies.

The benefit of this focus extends far beyond the simple adherence to our previously established definition. A significant level of energy infrastructure is already in place. Thus, to experience any meaningful benefits, this existing infrastructure has to be dealt with.

Much of the current energy provision and consumption comes from coal, and will continue to do so far into the future.[125] Coal can be used to generate electricity day or night, rain or shine, at a price that people can afford. Thus, it is an appealing fuel and is in widespread use. As Figure 4 indicates, coal supplies approximately 49% of total U.S. energy needs.[126]

Figure 4

U.S. Net Electricity Generation, 2008 (Million MWh)

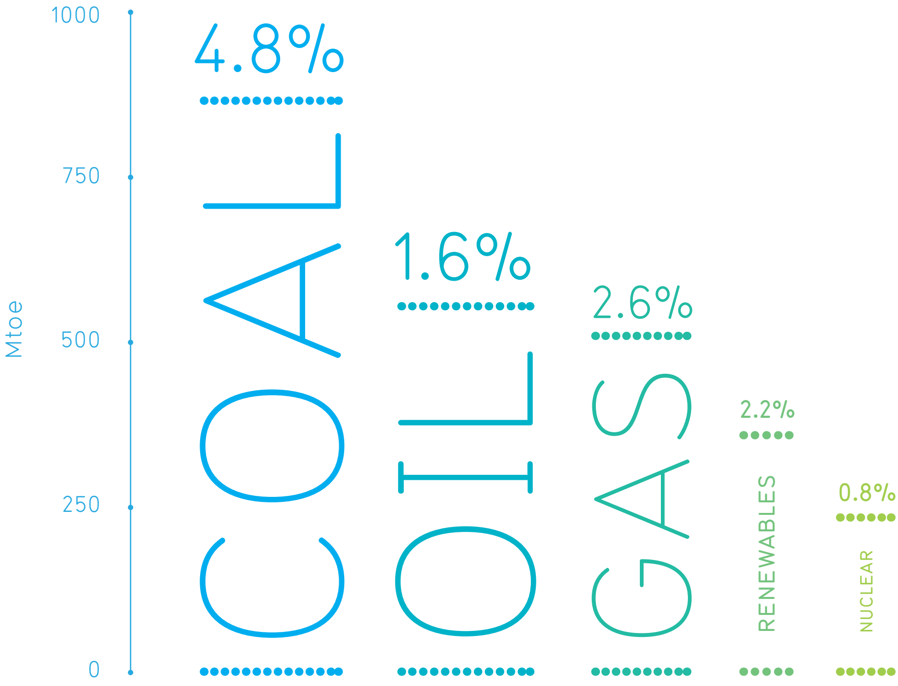


Source: Energy Information Administration

Coal's percentage is much higher in other countries. For instance, China utilizes coal for about 70% of its total energy consumption.[127] In fact, China has enough coal to sustain its economic growth (at current rates) for a century or more. Overall, the countries of non-OECD Asia (including China) account for 90% of the projected increase in world coal consumption from 2006 to 2030.[128]

In addition to the existing infrastructure already in place, energy providers around the world are building dozens of old-style coal plants that will cement the industry's standing as the largest industrial source of greenhouse gases for years to come.[129] More than 30 traditional coal plants have been built since 2008 or are under construction.[130] Coal's average demand growth over the past five years was 3.5 percent, much faster than for oil or natural gas.[131] The extra coal the world burned in 2009 relative to 2004 was about equal to the entire energy consumption of Germany and France in 2009 combined.[132] Figure 5 illustrates how between 2000 and 2007, coal demand grew at a rate more than double that of renewable fuels.[133]

Figure 5
Increase in Primary Demand, 2000-2007
% = Average Annual Rate of Growth



Source: International Energy Administration

Potential Technologies to be Deployed

The reinvention of fossil fueled power plants requires extensive, bold experimentation. The Integrated Energy Test Center will facilitate this experimentation by providing a working environment for research and testing in not just one but numerous areas that will be critical to the future viability and affordability of the electric sector. Currently envisioned areas include:

- An end-to-end carbon utilization center that would serve as the cornerstone of the test center;
- Constituent emissions detecting and removal;
- Steam cycle enhancement;
- Testing for a variety of electric and environmental equipment manufacturers; and
- A broader scope of integrated carbon work, including soil carbon enhancement.

International Carbon Utilization Center (ICUC)

The cornerstone of the Integrated Energy Test Center will be the International Carbon Utilization Center (ICUC).

The ICUC will complement the existing government-supported National Carbon Capture Center (NCCC), which is a proven technology accelerator in the area of mostly conventional carbon capture. It will particularly complement the Post-Combustion Carbon Capture Center (PC4) located within the NCCC.

The NCCC focuses on evaluating emerging, mostly conventional capture technologies, in isolation without sequestration or reuse. The ultimate goal of these capture improvements is to reduce the overall cost of CCS. This facility provides opportunity for individual solutions to test their process with incremental improvements.

In contrast to the NCCC, the ICUC will focus on developing unconventional capture techniques which when integrated with developing carbon utilization processes will create and optimize end-to-end solutions.

The ICUC will be dedicated to lowering the overall cost of capturing and utilizing CO_2 and to the overall emergence of carbon management solutions that provide for low-carbon, affordable and reliable power generation. The ICUC will provide a wide range of equipment and commercially representative test conditions that allow demonstration results to be scaled confidently to commercial application. Convenient access to scalability is a crucial element in shortening development time.

The slipstream associated with the ICUC can be also deployed to support other research and testing at the Integrated Energy Test Center in addition to carbon utilization, thus providing a collaborative research model that can be expanded in ways not as yet developed.

For ICUC purposes, to avoid overlooking emerging technologies still in early development, a screening process will be implemented to evaluate both small (lab/bench) scale and large (pilot/engineering) scale on separate tracks and leverage the activities taking place at the facility (see the final sections on "Activities" and "Layout"). This approach will provide a balanced portfolio promoting the advancement for both near-term and long-term candidate technologies.

The factors influencing ICUC objectives include cost reduction, fuel flexibility, short-term commercial implementation and long term potential. Budget considerations affecting qualitative screening criteria include project funding level, cost of testing, cost of developing, and ease of accommodation. The screening process will help NCUC focus on technologies that have the greatest impact in the near term without losing sight of other more advanced technology options that present greater long term potential.

Post-Combustion Carbon Capture

Current carbon capture technologies have focused on amines and chilled ammonia. These approaches were developed decades ago for use in other industries, such as synthetic ammonia production, H_2 production, and limestone calcination, where they have served these industries well given the relatively low volumes of carbon captured and high price points.[134]

Yet now that the power industry is examining carbon capture approaches and experimenting with scaling up these existing technologies to meet their volumetric needs and price-points, the industry is realizing that these traditional technologies are falling short. Furthermore, the current requisite hundreds of millions of dollars of investment required to capture and separate CO_2 must be radically reduced for carbon capture from power plants to be viable.[135]

In order to spur advancements, governments around the world have provided billions of dollars in funding to support the development of carbon capture breakthroughs. In the United States, the Department of Energy (DOE) has been actively funding technological development of advanced technologies for a decade, and has dramatically increased its level of financial support in recent years, largely through its National Energy Technology Laboratory (NETL) and Advanced Research Projects Agency-Energy (ARPA-E).[136]

A 2012 Prize Capital publication illustrates that a variety of technologies are emerging that introduce new approaches to carbon capture geared specifically towards large point-source CO_2-emitting sources, rather than simply scale-ups of older applications in different industries. These technologies – which include new solvents, enzyme based systems, physical sorbents, precipitated calcium carbonate, ionic liquids, gas separation membranes, and metal organic frameworks – have the potential to break through the energy, water, and cost barriers that afflict traditional carbon capture technologies.[137]

The vision of the ICUC is not only to offer a platform for a significant number of these emerging carbon capture technologies to cost-effectively deploy, demonstrate, and perfect their approaches, but to force the interaction between these new approaches with the ICUC's carbon recycling platform, which is described below, to foster innovation and lead to a scalable end-to-end CO_2 solution.[138] The ICUC will focus not only on technologies that capture carbon at the 12 percent concentration levels typical at coal-based power plants, but also at the 6 percent concentration levels typical at natural gas based power plants.

Carbon Recycling

Carbon capture and recycling (CCR) refers to the capture of industrially sourced CO_2 emissions and subsequent use of these emissions as a feedstock for the production of new products, such as fuel, building materials, animal feed, specialty chemicals, and plastics, among others.

In late 2011, Prize Capital, with the support of Tri-State, released a comprehensive Carbon Capture and Recycling (CCR) Industry Overview publication – the first of the syndicated series – that detailed this emerging industry. As outlined in the publication, the industry's technologies fall into three categories: biological, chemical and catalytic, and mineralization. The publication identified, profiled, and provided contact information for 136 different entities working on various CCR approaches: 37 biological, 63 chemical and catalytic, 23 mineralization, 1 blended approach, and 12 uncategorized entities.[139]

In addition to 136 CCR entities, the publication recognized the attention that the biological category has received in recent years by not only profiling the 37 biological entities that are either applying or have applied their technologies to the utilization of power plant flue gas, but also providing names, descriptions, and contact information of an additional 260 biological companies, universities, and laboratories in an appendix that have the potential to utilize flue gas but aren't known to explicitly do so at this time.[140]

Altogether, the CCR entities varied in size from unfunded concept to over $50 million in funding received. They're being developed within private companies as well as at universities and laboratories around the world. They have received government and private funding totaling approximately $1 billion. Some are offering full spectrum solutions from capture to reuse, while others focus only on reuse and need viable capture solutions to realize their potentials.[141]

The challenges associated with commercializing and deploying CCR technologies include: being able to recycle carbon year round, in various climactic conditions; thermodynamic and thermochemical logistics and efficiencies; scalability; proximity to necessary resources; as well as others.[142]

Each of these barriers is tied to the fact that very few CCR entities have access to a facility by which they can test, prove, and refine their technologies. Most of them are too early stage to convince energy producers to make a single technology demonstration bet on them, as has been done for CCS technologies.

Thus, access to real-world testing conditions for multiple CCR technology developers – of various sizes and levels of development – could potentially catalyze the development and deployment of this emerging platform.

Enhanced Oil Recovery – "EOR Plus"

Crude oil development and production in U.S. oil reservoirs can include up to three distinct phases: primary, secondary, and tertiary (or enhanced) recovery. During primary recovery, only about 10 percent of a reservoir's original oil in place is typically produced. Secondary recovery techniques extend a field's productive life generally by injecting water or gas to displace oil and drive it to a production wellbore, resulting in the recovery of 20 to 40 percent of the original oil in place.[143]

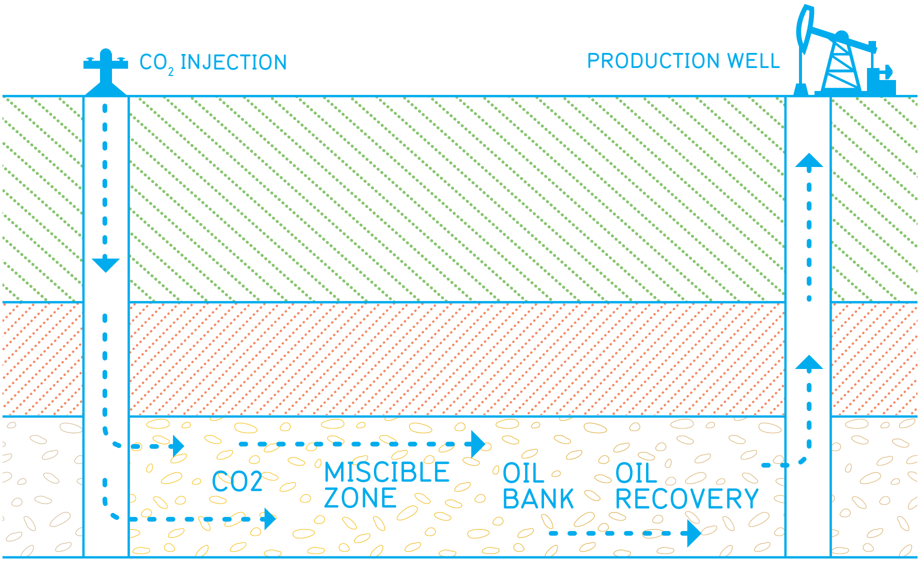
However, with much of the easy-to-produce oil already recovered from U.S. oil fields, producers have attempted several tertiary, or enhanced oil recovery (EOR), techniques that offer prospects for ultimately producing 30 to 60 percent, or more, of the reservoir's original oil in place. Three major categories of EOR have been found to be commercially successful to varying degrees: Gas injection; thermal recovery; and chemical injection.[144]

Gas injection uses gases such as CO_2 that expand in a reservoir to push additional oil to a production wellbore, or other gases that dissolve in the oil to lower its viscosity and improves its flow rate. Gas injection accounts for nearly 60 percent of EOR production in the United States.[145]

Gas injection EOR is not new. First tried in 1972 in Scurry County, Texas, CO_2 injection has been used successfully throughout the Permian Basin of West Texas and eastern New Mexico, and is now being pursued in Kansas, Mississippi, Wyoming, Oklahoma, Colorado, Utah, Montana, Alaska, and Pennsylvania.[146][147] In the U.S., there are about 114 active commercial CO_2 injection projects that together inject over 2 billion cubic feet of CO_2 and produce over 280,000 BOPD.[148]

Yet despite this experience, barriers remain to the long-term utilization and deployment of EOR, each of which the Integrated Energy Test Center can provide a platform to help overcome.

Figure 6
CO_2 Enhanced Oil Recovery



Source: Integrated CO2 Network (ICON)

The first barrier is tied to the cost of carbon capture, which was previously covered in Prize Capital's Emerging Carbon Capture Technologies Overview (2012). Impressively, CO_2 based EOR is already a commercially viable approach. Yet historically, most of the CO_2 used for EOR has come from naturally occurring CO_2 reservoirs. New technologies are being utilized so that CO_2-based EOR can be deployed in locations where naturally occurring reservoirs are not available. The pursuit and development of new carbon capture technologies can assist and ensure the financial profile of these expanded EOR deployments.

It's worth highlighting the synergy between EOR applications, which are commercially viable, and the essential development and testing required for new carbon capture technologies, which currently aren't commercially viable. Both parties – EOR project developers and carbon capture innovators – potentially have much to gain by working together, and the Integrated Energy Test Center offers an effective format for sifting through combinations of technologies and approaches to find appropriate matches.

It's also worth noting that in addition to carbon capture advances, EOR is ripe for advancement in other areas that can help improve its profile. In September 2010, the United States Department of Energy competitively selected seven CO_2 EOR research projects focused on tapping non-natural (i.e. industrial) CO_2 sources for EOR. Four projects will develop techniques for mobility control of the injected CO_2, one project will investigate the potential for oil production by CO_2 injection into the residual oil zone, and two projects will develop simulation and modeling tools for CO_2 EOR.[149] Given that the Integrated Energy Test Center will become the world's first "integrated energy" test center, seeking to facilitate complete solutions, each of these – and other emerging EOR-enhancing technologies – are appropriate for deployment, testing, and perfection at the Integrated Energy Test Center.

A second barrier to the long-term utilization and deployment of EOR comes from the legal uncertainty associated with long-term sequestration of CO_2. There has been limited attention paid to how to structure legal liability for the short-term or long-term risks associated with the geologic sequestration of CO_2 in connection with CCS and EOR.[150]

As it currently stands, existing federal and state environmental and tort liability regimes are insufficient on their own to govern the CCS industry.[151] The federal governments in the United States and Canada have not developed legislation to address the issue.[152] The holes presented in the current regulatory structure have led some to conclude that public nuisance lawsuits, which can be brought against anything injurious to health, or indecent, or offensive to the senses, or an obstruction to the free use of property so as to interfere with the comfortable enjoyment of life or property,[153] may at some point be filed against those storing CO_2 underground.

The likelihood and the legitimacy of these public nuisance lawsuits cannot be assessed given the fact that suitable regulatory and legislative direction is not in place. What can be stated is that any future potential lawsuit that has odds of occurrence greater than zero presents a fiduciary matter to all parties involved, including but not limited to EOR project developers.

Thus, with its emphasis on CO_2 utilization and conversion, the Integrated Energy Test Center can provide the platform for EOR project developers and other affiliated parties to not only pursue advancements in EOR processes, but also to fulfill a fiduciary responsibility to pursue hedge approaches that can process stored CO_2 in the event that such CO_2 needs remediation.

We dub this approach, which combines advances in EOR processes with carbon utilization that could in essence tap stored base material (i.e. CO_2) to use in the production of new materials, "EOR Plus".

Embodied in EOR Plus is not only the liability hedge presented by combining advanced EOR with utilization approaches, but the opportunity presented by viewing EOR as a method to swap resources: one resource being oil, which is extracted, and the other resource being CO_2, which in essence is deposited in an underground CO_2 "bank". Under an optimistic scenario of carbon utilization technology advancement and deployment, utilization technologies could be deployed where EOR reservoirs lay to process the banked CO_2 and capitalize on an opportunity to produce additional CO_2-based product.

"CO_2 Asset Network" (CAN)

A powerful component that can augment the carbon-related activities at the Integrated Energy Test Center is the formation and engagement of a "CO_2 Asset Network", or "CAN".

Over the last two years, the efforts of Tri-State and its partners – as demonstrated by this and previous publications, as well as other activities – have been greater than any other known efforts to reframe carbon as an asset (rather than a liability) and to focus action on spurring breakthrough innovation for an end-to-end carbon solution.

These efforts have provided unique global visibility into which groups, organizations, and companies are undertaking various actions on this front, and what those specific actions are.

In late September 2012, An invitation-only Carbon Capture & Recycling Leadership Workshop was held in New York City in conjunction with the United Nations General Assembly, the Clinton Global Initiative, and Climate Week NYC. Over thirty world-renowned experts, organizations, and interests attended this Leadership Workshop. The attendees expressed significant demand for networking, intelligence, best practice sharing, re-branding, and collaboration on the topic of CO_2 as an asset. The CAN would respond to these demands and build off these initiating efforts.

The vision for the CAN is to be a member-funded network focused on increasing momentum for, inspiring engagement in, and feeding a wide variety of innovative, new technologies to the Integrated Energy Test Center (and related activities). It would also be an effective and unique forum for connectivity, knowledge sharing, and collaboration across sectors and geographies.

Specific activities for the CAN could include:

- Regular networking and activity-oriented summits at the Integrated Energy Test Center (and elsewhere);
- The establishment of a best-practice sharing forum, particularly around test center design, development, and operation;
- Identification of key content questions to address through research and intelligence sharing, thus shaping the scope of the utilization opportunity;
- Technology briefing, brainstorming, and feeding sessions focused on deploying the most innovative new technologies at the test center.

The CAN would be an opportunity for diverse – even commonly opposed – interests to rally around this common cause. Members of this group could include: utilities, the oil and gas industry, coal interests, industrial partners, service companies, sovereign interests, reinsurance companies, foundations, non-governmental organizations, and environmental groups.

Constituent Emissions Detecting and Removal

On December 16, 2011, the Environmental Protection Agency (EPA) signed a rule to reduce emissions of toxic air pollutants from power plants. Specifically, the Mercury and Air Toxics Standards (MATS) for power plants will reduce emissions from new and existing coal and oil-fired electric utility steam generating units (EGUs).

MATS will reduce emissions of heavy metals, including mercury (Hg), arsenic (As), chromium (Cr), and nickel (Ni); and acid gases, including hydrochloric acid (HCl) and hydrofluoric acid (HF). These toxic air pollutants, also known as hazardous air pollutants (HAPS) or air toxics, are known or suspected of causing cancer and other serious health effects.

MATS applies to EGUs larger than 25 megawatts that burn coal or oil for the purpose of generating electricity for sale and distribution through the national electric grid to the public. These include investor-owned units, as well as units owned by the Federal government, municipalities, and cooperatives that provide electricity for commercial, industrial, and residential uses.

Reduction of Hg and HAP emissions for electric utilities will require new technologies to convert, scrub, absorb and/or filter these emissions from the flue gas in order to meet the new standards. The new control technologies may pose operational difficulties at the plants, or may require high levels of maintenance. Capital and O&M (operating and maintenance) costs may also be high.

The Integrated Energy Test Center can facilitate the demonstration of new technologies for HAP emissions control at a utility coal-based power plant that offers superior performance and reliability compared to today's commercially available offerings. Potential solutions that could be tested at the Integrated Energy Test Center include:

- Advanced filter systems that reliably remove levels of particulate matter in excess of that achieved by electrostatic precipitators or baghouse systems.

- Advanced scrubber systems that address acid gases (HCl and SO_2), particulate matter and HAP's
- Conversion systems that alter or convert acid gases and HAP's into harmless materials through direct injection of a solid, liquid or gas into the flue gas stream.
- Absorption systems that capture acid gases and HAP's through direct injection of a solid into the flue gas stream.
- Fuel additives that result in a reduction of, or the improved collection and removal of acid gases (HCl and SO_2), particulate matter and HAP's.

Aside from whether current emissions control technologies can meet these stricter emissions levels, an open question is whether current emissions monitoring equipment is sufficiently sensitive to detect the lower emissions. The Integrated Energy Test Center can provide a demonstration platform for testing new emissions control and monitoring equipment being developed to meet the new regulatory emissions standards.

Through deployment and demonstration at the Integrated Energy Test Center, it is expected that these technologies will evolve with time, with improvements in efficiency, reliability and performance. New technologies will also emerge that demonstrate lower capital and O&M (operating and maintenance) costs.

Energy-to-Energy Applications

Graphite consists of weakly bonded layers of graphene, which is itself comprised of carbon atoms arranged in linked hexagons, measuring just one atom thick and therefore having just two dimensions.

Graphene has been touted as a miracle material. Graphene is said to be the strongest material ever measured (some 200 times stronger than structural steel), an improvement upon and a replacement for silicon (150+ GHz vs. 40 GHz), as well as the most conductive material known to man (100 times faster than copper).

Graphene does not have just one application, and is not restricted to being one material. As Professor Andre Geim, the co-holder of the Nobel Prize in physics for his work with graphene at Manchester University said, "A good comparison would be to how plastics are used."[154]

Potential graphene applications include:

- Faster and cheaper electronic devices that are thinner and flexible
- Production of composite materials – like how carbon fiber is currently used – through the incorporation into a matrix like a polymer or a metal.
- Ultrafast computer processors and transistors
- Very large capacity batteries and ultra-capacitors
- Graphene powder added to tires to make them stronger

About 200 companies and start-ups are now involved in research around graphene. In 2010, it was the subject of about 3,000 research papers. Samsung has been one of the biggest investors in research, in collaboration with South Korean Sungkyunkwan University. Samsung projects that there will be a dozen products on the commercial market using graphene in the next five years.

Two Russian-born Manchester University professors won the Nobel Prize for physics in October 2010, "for groundbreaking experiments regarding the two-dimensional material graphene". Graphene is projected to receive a one billion euro investment from the European Commission over the next 10 years.

However, what has been reported as "potential" seems to be - at the moment - just that, with few real-world examples of it working to replace other materials.

According to IBM, "The material itself does not have a band gap, an essential property [meaning that graphene cannot stop conducting and be 'switched off', making it unusable in this way]. The applications of graphene and the application of silicon are in different domains."[155]

Experts say the time horizon for graphene's replacement of silicon is a very long way off. The problem that scientists face is that these "miracle" properties have only ever been demonstrated on a very small scale.

It appears that the major focus of graphene to date has been on thinner, flexible, consumer electronics. The Integrated Energy Test Center aims to increase the development and application of emerging graphene technologies to energy production, storage, and distribution, specifically those that benefit energy producers.

The goal of this platform will be to spur innovators to synthesize graphene from what is currently waste or by-products created by traditional energy production processes. Examples of such waste and by-products include carbon dioxide, criteria emissions, coal ash, and wastewater. These innovators will then use the synthesized graphene to produce something the either generates, stores, or distributes electricity.

Steam Cycle Enhancement

An element of virtually all baseload power generating facilities – including coal, natural gas, nuclear, and others – is the production of steam. In this process, demineralized water is fed into boilers, which is heated by fuel, turned into steam, and used to spin turbines that produce electricity. Steam is fundamental to the production of electricity.

Within this cycle of steam production and utilization are opportunities for leveraging and improvement. Thus, a vision for the Integrated Energy Test Center is to offer a platform to innovators who are working to utilize or improve the steam cycle, and thus the overall performance and value of the generating station. Areas of focus can include:

- Leveraging: steam hosting for industrial purposes
- Improvement: heat steam recovery for energy output gains
- Augmentation: solar augmentation of the steam cycle

Leveraging: Steam Hosting for Industrial Purposes

There are many industrial purposes of steam including heating, sterilization, propulsion, atomization, cleaning, moisturization, and humidification. Thus, steam is a very useful component in the manufacturing process.

Given that power plants are large producers of steam, co-located facilities that utilize steam for industrial gains, particularly in the energy and clean technology sectors, could be highly symbiotic and mutually beneficial.

Adjacent to the Escalante Generating Station lies a 146,000 ft^2 co-located steam utilizing facility. This facility, a paper factory, currently accepts 814 million pounds per year of steam from Escalante and uses it to produce 625 tons of paper per year. In the paper making process, steam is fed into large metal cylinders to heat them. These hot cylinders are used as rollers, which then process and dry wet paper.

One potential at the Integrated Energy Test Center is to convert a portion or all of this existing paper production facility into a hub for innovators who are utilizing steam to either enhance the plant's performance, for some aspect of conventional or clean energy production, or for using CO_2 byproducts to combine with paper products to create new building materials. Given the diversity of potential applications and industries that could locate at the facility, significant industrial expansion could result.

Image 12

The existing paper production facility adjacent to the Escalante Generating Station could be retrofitted to demonstrate and test steam-utilizing energy technologies.

Source: Tri-State Generation and Transmission Association

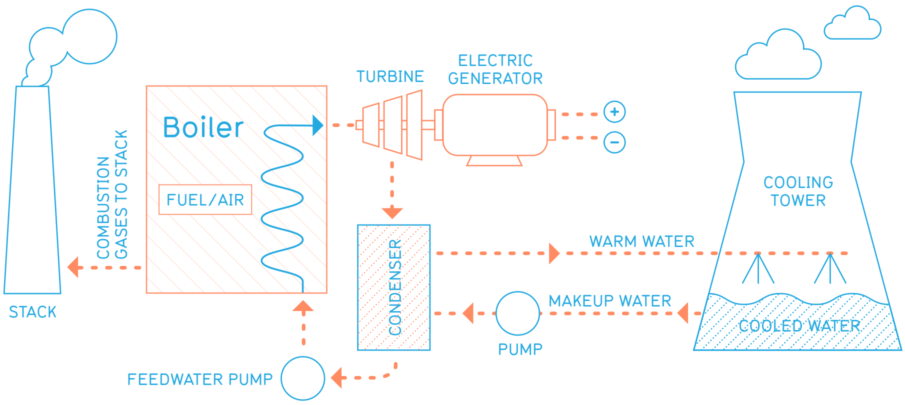
Heat Steam Recovery for Energy Output Gains

Heat steam recovery is a deliberately broad category that opens the door to the deployment and testing of virtually any technology that can be coupled with a generator's steam cycle to increase the aggregate level and efficiency of energy output.

As Figure 7 indicates, a large number of components are connected to a generating station's steam cycle. Demineralized makeup water is pumped into a condenser. This water is then pumped into the boiler, where it is turned into steam. This steam rotates a turbine, which in turn spins an electric generator to produce electricity. After departing the turbine, a cooling tower heat exchanger condenses the steam back to its liquid state and then reenters the boiler, where it vaporizes to steam, increases in heat and pressure, and once again returns to the turbine.

Figure 7

A generating station's steam cycle is integral to the plant's operation and is comprised of many components



Source: West Virginia University

Electricity producers work hard to maximize the efficiency of this process. General Electric states that enhancing the steam cycle "can reduce fuel consumption and associated CO_2 emissions by 3-5 percent."[156]

Despite this effort and potential, it is still nonetheless difficult for new, innovative steam cycle technologies to be tested, proven, and gain traction at real-world generating stations. Operators are cautious when it comes to tweaking such a critical portion of a generating station, and thus tend to rely on existing and proven technologies to meet performance benchmarks.

The Integrated Energy Test Center can change this scenario by offering a platform for innovators of a variety of new technologies and approaches that can enhance heat steam recovery and internal efficiency to showcase their technologies in a single location. The doors would be open for innovation within virtually any component in the steam cycle and general boiler efficiency improvements. Various focal areas could include:

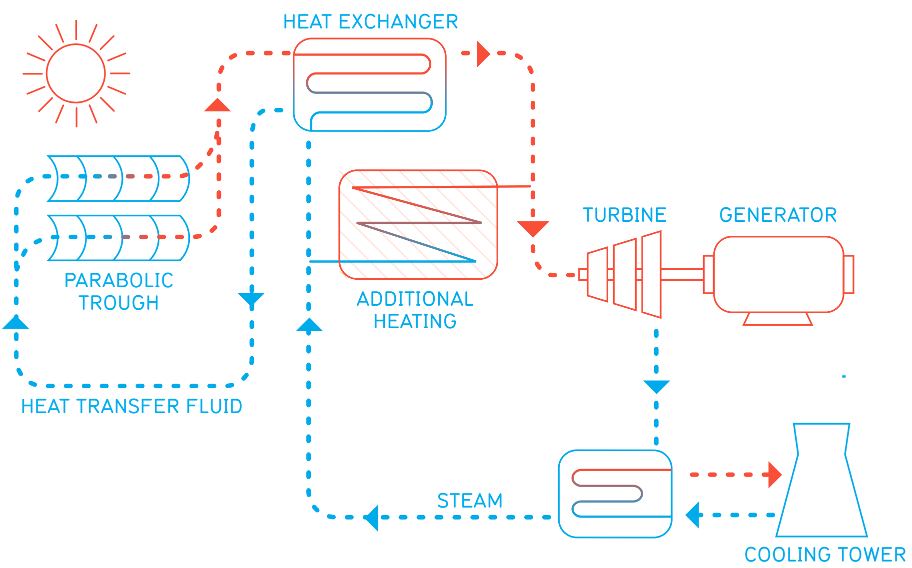
- Air leakage into boiler;
- System integrity;
- Improved boiler refractory;
- Burner management and enhancement;
- Optimization of air injection direction (to reduce NOx);
- Maintenance and integrity of feed water heaters (to remove leaks, etc.);
- Improvement of feed water heater energy transfer; and
- Enhancements to the performance and durability of the air duct fan.

Solar Augmentation of the Steam Cycle

Coal (and other fossil fuels) is but one of many ways to fuel the production of steam. Another way is by utilizing renewable energy. If steam can be created via a renewable source adjacent to a generating station, this steam can be fed into the station's existing steam cycle to power the turbine and produce electricity. This production of steam and electricity displaces the conventional fuel and thus can lower the environmental footprint of the generating station.

A primary renewable energy for steam cycle augmentation is solar thermal, also known as "concentrating solar power" (CSP). CSP technologies use mirrors to reflect and concentrate sunlight onto receivers that collect solar energy and convert it to heat. As Figure 8 illustrates, CSP plants produce power by first using mirrors to focus sunlight to heat a working fluid. Ultimately, this high-temperature fluid is used to spin a turbine or power an engine that drives a generator. The final product is electricity.[157]

Figure 8
A typical process of solar thermal steam cycle augmentation



Source: Best Technology

Solar augmented steam cycle facilities can offer a value to energy companies such as:[159]

- Adds utility-scale solar power generation without the significant challenges of siting a new plant and developing a new power block;
- Utilizes existing plant assets, improving performance and increasing longevity;
- Contributes to green power programs and reduces CO_2 footprint;
- Develops experience with solar thermal technologies to assess future potential in generation mix.

In 2009, Tri-State entered into an agreement with the Electric Power Research Institute (EPRI) to host a case study that was aimed at helping electric utilities add solar energy to fossil-fueled generating stations. Escalante Station was the host facility for the study.[160]

The project provided a conceptual design study, analyzed options to retrofit the existing power plant, and identified new plant design options. EPRI relied on its expertise in solar technologies, steam cycles and plant operation, as well as past solar and fossil fuel plant studies.[161]

During the case study, solar thermal research engineers at the U.S. Department of Energy's Sandia National Laboratory in Albuquerque, New Mexico, and the National Renewable Energy Laboratory (NREL) in Golden, Colorado analyzed the system's performance.[162] The results indicated the potential that a CSP array at Escalante Station has in increasing power plant efficiency while incorporating renewable technologies. Yet in order to move forward, cost-competitive CSP systems need to be identified and demonstrated, which makes solar augmentation of the steam cycle at Escalante Station an ideal component for inclusion in the Integrated Energy Test Center.

Coal Processing

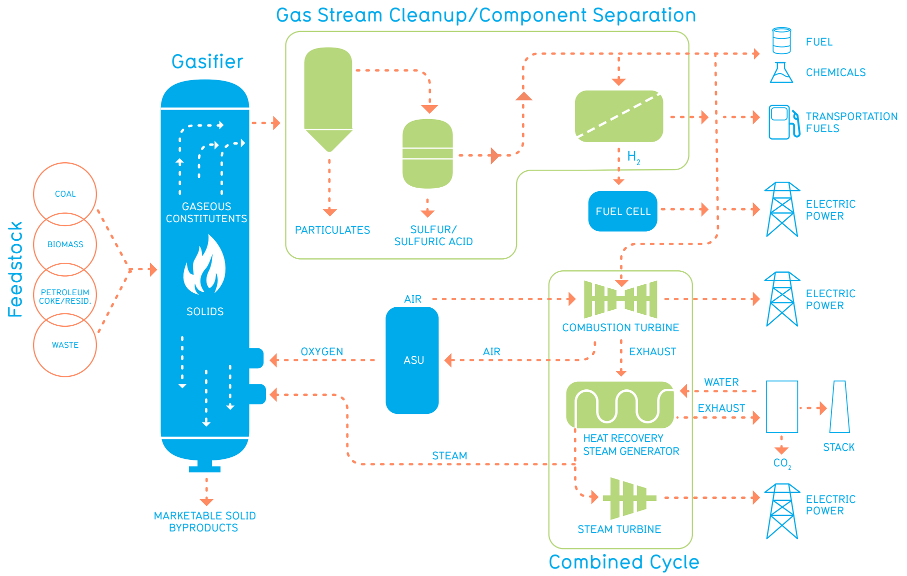
An additional reason why Escalante Station is ideal for IETC integration is that it sources its coal reasonably close to the station.

While the local coal provided by this mine requires minimal processing before delivery to Escalante Station, coal from other mines around the world may require additional and advanced upgrading before it can be used. Thus, the Integrated Energy Test Center can add value by hosting emerging coal-processing technologies, providing them with coal, and demonstrating their technologies and approaches.

Virtually any technology and process associated with coal handling, preparation, and processing can be appropriate for testing and demonstration at the Integrated Energy Test Center. A technology platform of particular interest is coal gasification. Coal gasification offers one of the most versatile and clean ways to convert coal into electricity, hydrogen, and other valuable energy products.[163]

Rather than burning coal directly, gasification (a thermo-chemical process) breaks down coal – or virtually any carbon-based feedstock – into its basic chemical constituents, as depicted in Figure 9. In a modern gasifier, coal is typically exposed to steam and carefully controlled amounts of air or oxygen under high temperatures and pressures. Under these conditions, molecules in coal break apart, initiating chemical reactions that typically produce a mixture of carbon monoxide, hydrogen and other gaseous compounds.[164]

Figure 9
Gasification-Based System Concepts



Source: National Energy Technology Laboratory

The Energy Department's Office of Fossil Energy is working on coal gasifier advances that enhance efficiency, environmental performance, and reliability as well as expand the gasifier's flexibility to process a variety of coals and other feedstocks.[165] Thus, the Integrated Energy Test Center could leverage this other work being done to advance this approach, providing additional value to the platform and working more efficiently to advance commercialization.

Another technology platform of particular interest is coal dewatering. Efficient dewatering of coal is one of the highest priorities in production encountered by coal preparation engineers. The objectives may be to meet product specifications or environmental constraints or to facilitate the handling of coal and tailings. Reduction of fine coal moisture has become a major concern as the amount of fine coal increases together with pressures to process it.[166] Because there has been no economically viable technology to remove water from ultrafine coal slurries, the ultrafine particles that are the residue of the coal cleaning process have been discarded into hundreds of impoundments.[167]

Innovators have already begun working to find innovative, economically viable methods to dewater coal. With funding from NETL, researchers at Virginia Tech have developed a hyperbaric centrifuge that can efficiently dewater coal as fine as talcum powder. The hyperbaric centrifuge is like the spin cycle on a washing machine, with the addition of compressed air. The researchers claim that combining increased spinning and compressed air has a synergistic effect and cuts the moisture in half compared to conventional technology.[168]

The Integrated Energy Test Center can attract and host these and other emerging coal processing innovators, provide them with the fine coal and/or tailings and other resources that they need, and offer them a real world testing facility to rapidly commercialize.

Soil Carbon Enhancement

An integrated energy test center allows the rescoping of addressed areas. At the Integrated Energy Test Center, the scope of carbon will be broadened not just to include previously mentioned end-to-end solutions, which capture then utilize the carbon, but also parallel issues that affect carbon and are affected by carbon.

One such targeted issue is the relationship between carbon and soil.

For millions of years, plants and soil microbes have helped regulate CO_2 levels in the atmosphere. As plants grew, some of their carbon transferred from the roots to symbiotic fungi and soil microbes, which stored the carbon in the soil as humus. When plants died, their root systems added to soil carbon stores and their above ground matter created a layer of mulch which inhibited CO_2 volatilization.

Agriculture, which began about 10,000 years ago, reduces the on-going transfer of CO_2 from plants to soil that occurs in natural habitats. Over millennia, as agriculture intensified, carbon stores (in the form of biomass) were volatilized when natural habitat was converted for farming. Plowing and soil tillage contributed to the volatilization of soil carbon and nitrogen as well.

So farming not only disrupted carbon sequestration, it also became one of the most significant sources of CO_2 emissions.

Globally, half of all topsoil has been lost since the advent of the Industrial Revolution.

Some agricultural soils have lost 70 to 90 percent of their embedded carbon and hundreds of millions of hectares have been abandoned due to severe degradation.

The Integrated Energy Test Center can assist with the identification and promulgation of technologies and techniques that reconnect and rebalance carbon levels in soil. One hypothesis is that there may even be a way to go from “stack to soil”, whereby CO_2 from the facility’s resident smokestack can be harnessed as a soil additive, and concurrently remediate two problems. By facilitating and encouraging soil carbon innovators’ access to facility resources, the aim is to test this and many other soil carbon hypothesis, while in the process providing broadened value as a truly integrated energy test center.

Design

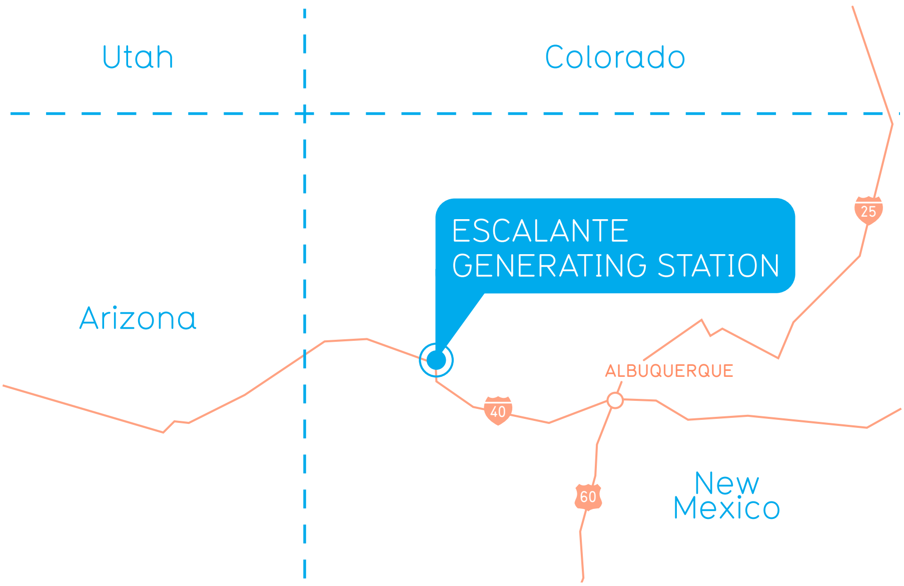
Tri-State has performed significant design work and planning for the Integrated Energy Test Center and hosting it at Escalante.

Location

The Escalante Generating Station is a 250 MWe tangentially-fired pulverized coal boiler built by Combustion Engineering in 1984. It operates at 1800 psig 1005°F and 1,800,000-lb./hr. steam flow. The boiler burns New Mexico sub-bituminous coal at about 9,000 Btu/lb. The boiler has a bag house for particulate control and a wet limestone scrubber for SO_2 control.

Image 13

The future home of Integrated Energy Test Center at the Escalante Generating Station, 105 miles west of Albuquerque, NM



The Escalante Generating Station is located in Prewitt, NM, twenty-seven miles northwest of Grants, NM about 105 miles west of Albuquerque. Albuquerque is the largest city in the state of New Mexico with a metropolitan population of 900,000. Albuquerque is the home to the University of New Mexico, Kirtland Air Force Base, and Sandia National Laboratories.

The Escalante plant site is solely owned by Tri-State and has land, water/wastewater, electric, and highway and rail access with substantial landmass with ample room for expansion of Integrated Energy Test Center facilities.

Image 14

The entrance to the Escalante Generating Station

Source: Tri-State

The Escalante facility has interstate highway, railroad access, and international airport access within one and one-half hours. The Escalante Generating Station was chosen as the host location given these attributes as well as the fact that it is representative of modern, reliable coal power facilities. Thus, its reasonable to expect that the technologies perfected at Escalante will be relevant for global deployment.

Overview – Grants, NM

Location:	Seat of Cibola County, central-western New Mexico
City Population:	9,182 (2010 census)
County Population:	27,213 (2010 census)
County Size:	4,542 sq mi (11,763 sq km)
Time Zone:	Mountain Standard Time (7 hours earlier than GMT)
Elevation:	6,460 ft (1,969 m)
Geography:	Primarily mountains and high desert, dominated by sandstone and lava flows
Economic Legacy:	Railroad camp, logging, agriculture, uranium mining, tourism (Route 66)

Transportation to/from Escalante

Road:

Located on U.S. Interstate Highway 40, approx. 80 miles/1 hour west of Albuquerque, NM (pop. 898,000 metro); 500 miles/8 hours southwest of Denver, CO (pop. 2.6 million metro); 400 miles/6 hours northeast of Phoenix, AZ (pop. 4.2 million metro); and 700 miles/12 hours east of Los Angeles, CA (pop. 12.8 million metro).

Air:

Served by Grants-Milan Municipal Airport (publicly owned; 2 runways; services single engine and multi-engine aircraft but no commuter airlines; elevation of 6,537 ft.)

Approximately 85 miles west of Albuquerque International Sunport, which is served by most major U.S. and regional airlines.

Rail:

Located along major east-west BNSF freight route to the West Coast.
Located along Amtrak Southwest Chief route (stations in Gallup and Albuquerque).

Research Institutions Near Escalante

Los Alamos National Laboratory (www.lanl.gov)

- Los Alamos – 175 miles/3 hours away
- U.S. DOE facility; one of two federal labs doing classified work on the design of nuclear weapons.
- Conducts multidisciplinary research in fields such as national security, space exploration, renewable energy, medicine, nanotechnology, and supercomputing.
- Employs approximately 9,000 direct employees and around 650 contractor personnel.

Sandia National Laboratories (www.sandia.gov)

- Albuquerque – 80 miles/1 hour away
- DOE-funded R&D center operated by Lockheed Martin subsidiary Sandia Corp.
- Focus areas are Nuclear Weapons; Defense Systems & Assessments; Energy, Climate & Infrastructure Security; and International, Homeland & Nuclear Security.
- Energy Security program "works to reduce the risks of transformative energy solutions that will enhance the nation's security and economic prosperity."

University of New Mexico (www.unm.edu)

- Albuquerque – 80 miles/1 hour away
- State flagship university, offering more than 215 degree and certificate programs, including 87 bachelor's degrees, 72 master's degrees and 38 doctoral programs.
- Nationally ranked electrical engineering and chemical engineering programs.

New Mexico State University (www.nmsu.edu)

- Las Cruces – 280 miles/4 hours away
- Engineering College includes research initiatives in water, energy, aerospace, transportation and information sciences.
- Branch campus in Grants.
- Houses New Mexico Water Resources Research Institute

New Mexico Institute of Mining & Technology (www.nmt.edu)

- Socorro – 130 miles/2 hours away
- Associate's, bachelor's, master's and doctoral degrees in science and engineering.
- All engineering seniors complete "capstone" projects, often working with off-campus sponsors who present challenging projects.

Santa Fe Institute (www.santafe.edu)

- Santa Fe – Approx. 140 miles/2 hours away
- Private, non-profit research institute founded in 1984 by former Los Alamos Lab fellow.
- Focus is on the science of complex adaptive systems.

Provisions

The Integrated Energy Test Center and its cornerstone, ICUC, are designed to support the development of multiple post-combustion CO_2 capture and utilization technologies.

The site will be designed to provide several parallel paths to test candidate processes at appropriate scales. The facility will provide various slipstream sizes for small-scale tests as well as support integration of test skids developed by outside technology developers. The facility will host events and meeting requirements of researchers and vendors testing solutions.

If required, the slipstream available for testing, initially at 20 to possibly 40MW, could be increased to as much as 250MWe.

Activities

In addition to events and meetings, activities are planned for the Integrated Energy Test Center to leverage its provisions and maximize its potential.

Several of these activities take the form of inducement prize competitions. Inducement prizes have been used as a tool to spur innovation for centuries. Inducement prizes offer unparalleled leverage to create radical breakthroughs. Rather than funding research with unclear results, large prospective inducement prizes encourage the best minds to focus and then solve a well-defined problem. The efficiency of the approach attracts corporations, entrepreneurs and maverick thinkers to develop alternative approaches to solving major problems. Several examples of successful prizes are:

- 1714: The British Parliament creates a series of large cash awards, or "Longitude Prizes," for an accurate means of determining time while at sea, which stimulated discoveries that revolutionized ocean navigation.

- 1775: The French Academy of Sciences offers a prize for a process to convert salt to sodium carbonate. When the discovery was made in 1795, it stimulated the modern chemistry industry.

- 1919: French-American hotelier- Raymond Orteig offers a prize for the first non-stop flight between New York and Paris, won in 1927 by Charles Lindbergh, whose flight triggered rapid growth of the commercial aviation industry.

- 1993: A group of 25 utilities, representing a quarter of the nation's electric customers, offer the "Golden Carrot Prize" to hasten the commercialization of energy-efficient, less-polluting refrigerators. As a result, enough energy was saved in 2005 alone to avoid greenhouse gas emissions equal to those from 23 million cars — all while saving $12 billion in utility bills.

- 1995: The Ansari X PRIZE, established by an American entrepreneur, rewarded the first team to fly build a rocket ship that was able to 100 kilometers twice within a two- week period. This was accomplished in 2004. Moreover, this $10 million prize leveraged over $100 million in direct investment by companies chasing the prize and created a $1.3 billion industry.

- 2011: The Wendy Schmidt Oil Cleanup X Challenge inspired entrepreneurs, engineers, and scientists worldwide to develop innovative, rapidly deployable, and highly efficient methods of capturing crude oil from the ocean surface. 37 teams entered the competition, hoping to win a piece of the $1.4 million in prize money offered. The winning teams were required to demonstrate the highest ability to recover oil on a seawater surface at the highest Oil Recovery Rate (ORR) above 2,500 gallons per minute with an Oil Recovery Efficiency (ORE) of greater than 70 percent. The first place winner exceeded the ORR target by 87% and the ORE target by 28%.

This activity does not show any signs of waning. For instance, NASA has received congressional approval for $250 million in prize money for the "Centennial Challenges," Congress has approved $100 million in prize money related to the production of hydrogen, and the X PRIZE Foundation has launched a suite of prizes aimed at benefiting humanity.

The first planned tenant of the Integrated Energy Test Center is the Tri-State Carbon X PRIZE. The Tri-State Carbon X PRIZE competition is a high-stakes, high reward competition that challenges technical teams to create useful and valuable products from fossil fuel generation effluent, including coal and natural gas and for all fossil dependent industries, not just electricity production.

The goal of the Tri-State Carbon X PRIZE is to validate at a commercial scale new technologies and products that make capturing CO_2 from coal plants a revenue stream, not a liability. The first developer to achieve the rigorous competition criteria receives a $10 million reward. Additional competitions may be launched along the way, such as achieving CO_2 utilization from natural gas-fired production streams.

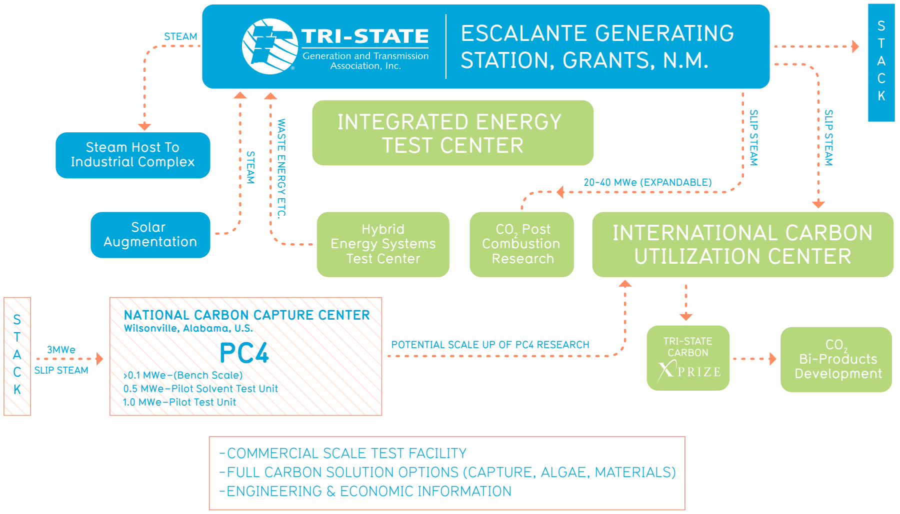
In addition to the Tri-State Carbon X PRIZE, challenges are being scoped in the areas of constituent emissions measuring and mitigation, energy-to-energy applications (such as graphene), and soil carbon.

Layout

Tri-State has engaged in significant planning and design work to create the Integrated Energy Test Center and ensure its seamless integration into the Escalante Generating Station. Space and resources are allocated for solar augmentation, hybrid energy systems, post-combustion carbon research, and the ICUC, as indicated in Figure 10.

Figure 10

The Integrated Energy Test Center affords numerous resources to innovators and seamlessly integrates into the Escalante Generating System



Conclusion

Test centers in general allow the side-by-side or sequential comparison of multiple, emerging energy technologies in true operating conditions. They can address "stack risk", which refers to the risk to existing permitting that a power plant assumes in order to test a new technology. Subsequently, they can reduce deployment costs as an initial blanket approach facilitates the testing of multiple approaches. With lower costs of development, they promote experimentation, innovation, and collaboration among participating innovators. Finally, energy test centers can enable cost effective scale-up by taking a more methodical, informed approach to deployment.

We can learn from the efforts of a broad array of existing test centers that a large opportunity exists both for energy providers and innovators through the creation of an integrated energy test center, which aims to leverage existing infrastructure while at the same time reinvent traditional energy production by creating "hybrid" platforms capable of meeting current and future societal needs.

Tri-State's efforts to create the world's first integrated energy test center represent the most significant and meaningful effort to seize this opportunity and create such a facility.

Land has been allocated adjacent to Tri-State's Escalante Generating Station to create the Integrated Energy Test Center, where multiple innovators can come and concurrently test their technologies. Envisioned testing platforms include the world's first end-to-end carbon utilization solution facilitator, as well as steam hosting for industrial purposes, heat steam recovery for energy output gains, solar augmentation of the steam cycle, constituent emission detection and removal, and other approaches supplied by equipment manufacturers.

When the Integrated Energy Test Center is complete, a new resource will be available to the world that has the potential to spur tremendous excitement and innovation in the world of energy production.

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