DRESSER-RAND®

Bringing energy and the environment into harmony.℠

COMPRESSED AIR ENERGY STORAGE (CAES)

Unique load management and generation “on demand”

Unmatched experience makes Dresser-Rand your partner of choice.

This CAES equipment built by Dresser-Rand has been performing reliably in McIntosh, Alabama since 1991.

FROM CAES PIONEER TO CAES LEADER

Dresser-Rand is uniquely qualified to deliver total demand management and power generation using Compressed Air Energy Storage (CAES) solutions. We designed and supplied the entire turbomachinery train and controls for the first CAES plant in North America. Only the second of its type in the world, Power South’s McIntosh, Alabama, USA facility has been building an impressive record of starting reliably more than 90 percent of the time, and demonstrating greater than 95 percent reliable operation since 1991.

FLEXIBLE SOLUTIONS FROM A SINGLE SOURCE

Dresser-Rand can supply the entire CAES train. Our teamwork reduces your project management time, and single-source packaging minimizes transaction and transportation costs.

We custom-engineer each CAES train to provide you with a system designed specifically to meet your site’s operating and geologic requirements. We select and fine-tune standard Dresser-Rand components for your project, then we make sure that all components will work together to maximize efficiency, and reduce installation and start-up times. Systems can be configured for salt caverns, hard-rock caverns, aquifers, or depleted natural gas fields on land or sea.

FUTURE OPPORTUNITIES FOR CAES SOLUTIONS

Ever alert to workable solutions, Dresser-Rand engineers recently secured a patent for a sub-sea CAES concept that combines a conventional CAES facility with a sub-sea piping and compressed air storage system. Such a structure could bring CAES technology to a wide range of coastal locations that represent nearly 80 percent of the world’s demand for electricity.

Furthermore, the growing interest in wind and solar energy has spurred interest in CAES technology. Wind farms typically generate more electricity at night when there already is a surplus of electricity. The ability to “bottle” this electric energy for daytime use (when it is most valuable) is an attractive consideration. Likewise, electricity from photo-voltaic farms in “sunny” regions could be sent through high-voltage DC transmission lines to CAES facilities elsewhere, where turbines would generate electricity year-round.

CAES technology gives utility operators the means to operate their base load plants more efficiently and provides a solution for balancing the grid. And it enables green technologies such as solar cells and wind turbines to be matched with daily and weekly demand requirements for electricity.

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Unmatched experience.

The only CAES plant operating in North America, the Power South facility continues to meet its peak load demands on a daily basis. To date, the train has started reliably more than 90 percent of the time, and demonstrated greater than 95 percent reliable operation (running).

As changing market forces make CAES increasingly attractive, this ongoing success makes the Power South plant's major equipment supplier, Dresser-Rand, the logical choice for developing the next generation of CAES facilities.

CAES Plant Builds Impressive Record

Since 1991, a CAES plant in McIntosh, Alabama has been producing up to 110 MW of electrical power during periods of high peak demand. The plant's owner, Power South, uses it to boost its power capabilities during the peak daytime periods when demand for electric energy skyrockets. "Our load is primarily residential," says plant manager Lee Davis. "CAES fits well with our load shape. Basically, I'm very much for the CAES concept."

The facility uses excess electricity generated by a Power South coal-fired plant during off-peak hours (when electricity costs are lowest) to compress air for storage. It then uses that air to generate electricity and sell it at a higher price during peak periods. "We buy low and sell high," Davis says.

"Normal startup for us is 14 minutes to reach 110 MW," says Davis. "I can run down to 10 MW. It's just a better regulating tool." A dispatcher controls both the plant's compression and power generation cycles via microwave from 90 miles away.

The 140-foot train, one of the longest in the world, is almost exclusively Dresser-Rand equipment. It is technically derived from Dresser-Rand product lines that have been time- and field-tested for decades in other applications. The equipment includes single-stage turbines, standard multi-stage turbines, packaged geared turbine generators and engineered turbine generators, centrifugal and axial compressors, gas turbines, and reciprocating compressors.

The train has a centrally located motor/generator with clutches on both sides. On one side, a low-pressure compressor, intermediate compressor and high-pressure compressor work to store air in a salt dome at pressures up to 1100 psig. Four stages of compression and three inter-coolers are used to enhance cycle efficiency by minimizing compressor power.

When electric power demand peaks during the day, the process is reversed. The compressed air is returned to the surface, heated, and run through high-pressure and low-pressure expanders to power the motor/generator to generate electricity.

Power South uses an underground salt dome for compressed air storage. "We solution mined it for 629 days," Davis recalls. "That created 19 million cubic feet of cavern storage."

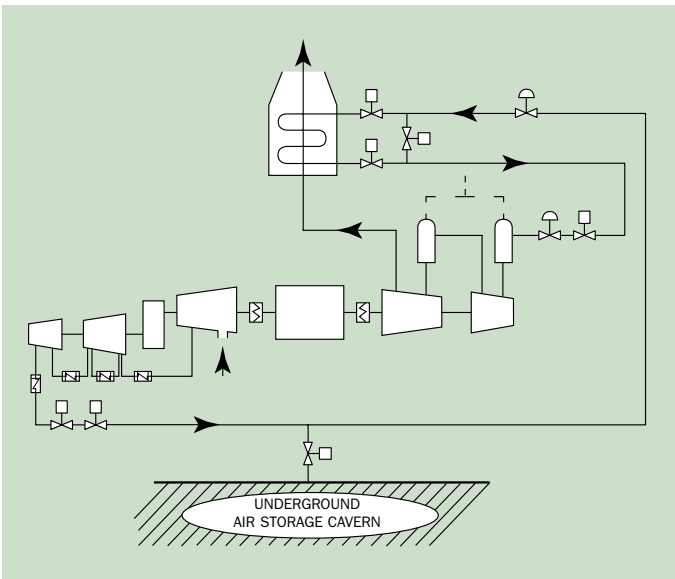
13-YEAR AVERAGE RELIABILITY			
COMPRESSION		GENERATION	
Starting	Running	Starting	Running
92.7%	99.6%	91.6%	96.7%

CAES

A Smart Choice for Many Utilities

Increases efficiency and extends base load unit life— CAES facilities enable you to optimize your base load units by minimizing load swings to maximize efficiency and extend unit life. Storing energy lets you use off-peak power to meet peak demand. This is less expensive than using traditional gas turbine peaking units or purchasing power from other sources.

Responds quickly—A CAES generator is designed to be started and brought to full load in as little as 10 minutes, eliminating the need for intermediate-load plants and providing a cost-effective way to meet spinning reserve requirements. CAES generators also have excellent load-following capability and very good part-load efficiency. Compressors can be engaged quickly to absorb load rather than reducing your base load generation.



Schematic of traditional CAES process showing air flow into and out of the storage cavern.

Flexible cycling options— The CAES system is available for compression duty when it's not in power generation mode, and can be configured for daily, weekly, or extended cycles. This allows you to "grid balance," and use inexpensive power for air storage (charging).

Environmentally friendly— CAES has environmental advantages compared to conventional gas turbines because its combustors use as little as two-thirds the fuel. Furthermore, CAES can be an attractive alternative to the costly modifications required to make coal-burning plants comply with increasingly stringent fossil fuel emissions requirements.

A CAES PRIMER

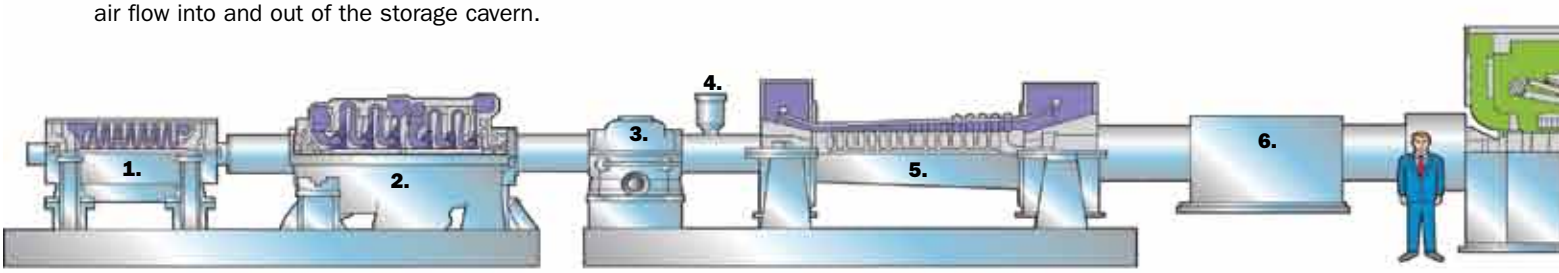
In a CAES plant, available off-peak electricity is used to power a motor/generator that drives compressors to force air into an underground storage reservoir at high pressures. This process (called "charging") usually occurs at night, and during weekends when utility system demands and electricity costs are low.

During intermediate electrical demand periods, the air is released from the reservoir, and without further compression is heated and expanded through gas- or fuel oil-fired combustion turbines to drive the same motor/generator to produce electrical power.

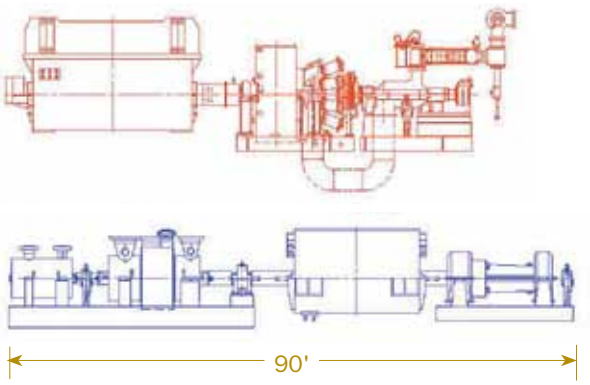
Compressed air may be stored in certain reservoirs created by solution mining bedded or domed salt formations; conventionally mining solid rock; or in aquifers and depleted natural gas fields. These formations can be found around the world.

LONG-TERM SERVICE AGREEMENTS (LTSA)

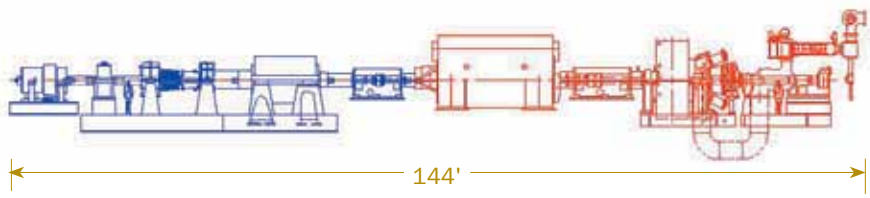
Dresser-Rand offers long-term service agreements (LTSA) to clients who require personnel to supplement or replace their maintenance organizations. A typical LTSA includes project management, technical services, field crews, and support from our OEM technical resource network. Our field teams are OEM-trained, fully equipped, committed to safety, and logistically prepared to provide professional and timely services to keep your critical equipment on-line, or restore it to full operation.



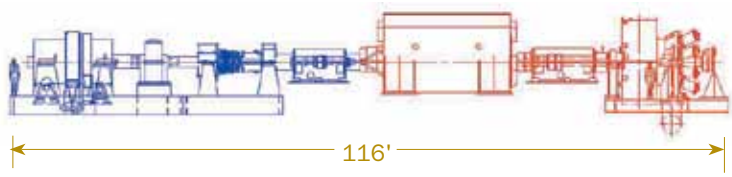
MODULAR DESIGN ALLOWS EACH SYSTEM TO BE CONFIGURED FOR MAXIMUM EFFICIENCY



Increased flexibility for simultaneous compression and power generation and quicker transition time between power generation and compression.



Matching power generation with compression flow requirements for air storage in salt domes or hard rock caverns.



Matching power generation with lower discharge pressure requirements for air storage in aquifers.

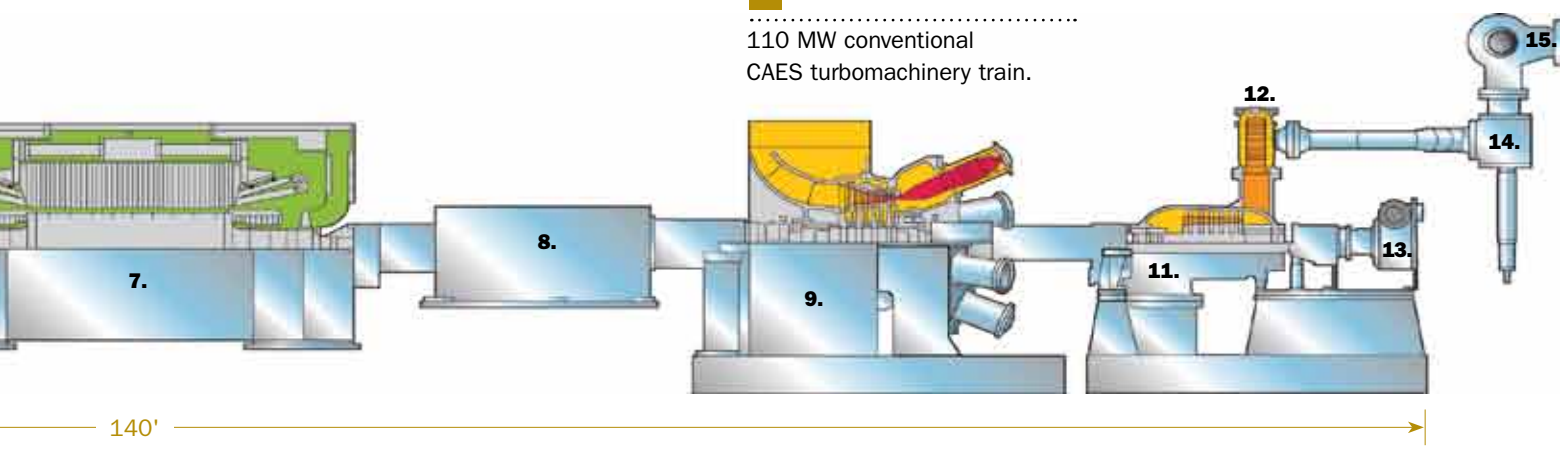
FLEXIBLE OPERATION TO MEET CUSTOM REQUIREMENTS

- Modular, single-shaft train uses proven equipment designed to meet stringent American Petroleum Institute (API) standards
- Flexible operation modes available
- Low operation and maintenance life cycle costs achieved by:
  - Smaller, less expensive turbine components
  - Standard modules and replacement parts
  - Longer time between overhauls (compared to conventional high-temp gas turbines)
  - Lower fuel consumption (less than two-thirds that of equivalent gas turbines)
  - Wide turn-down (load) with only moderate reductions in efficiency
  - Higher efficiency at partial load
- Only a portion of the plant capacity is lost if a module of the CAES system is down for maintenance (compared to plants with large steam turbine units)
- Incremental capacity—development of storage sites
- Short lead times
- Rapid start—in as little as 10 minutes to full load
- Motor/generator can be used as a synchronous condenser to improve the system's power factor
- Output not affected by ambient temperatures

LEGEND

1. High-pressure compressor
2. Intermediate-pressure compressor
3. Speed-increasing gear
4. Turning gear
5. Low-pressure compressor
6. Clutch
7. Motor/generator
8. Clutch
9. Low-pressure expander
10. Low-pressure combustors
11. High-pressure expander
12. High-pressure combustors
13. Turning gear
14. Air throttle valve
15. Air trip valve

110 MW conventional CAES turbomachinery train.



***SMART*CAES™**

Enhanced Renewable

Energy Solutions

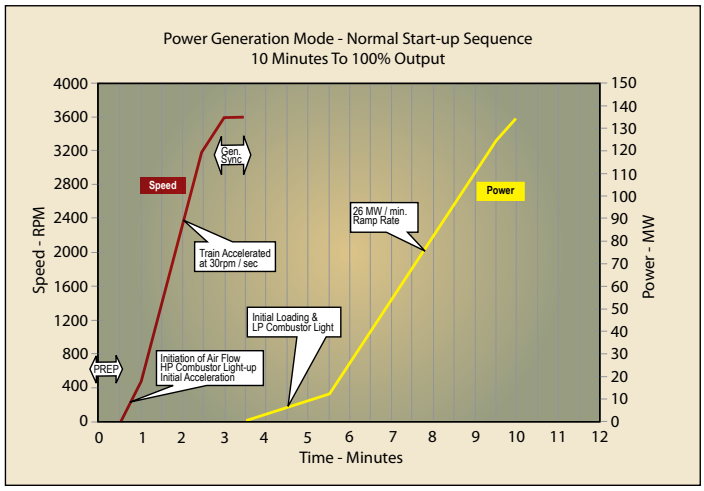


FIGURE 1: Power generation mode—normal start-up sequence

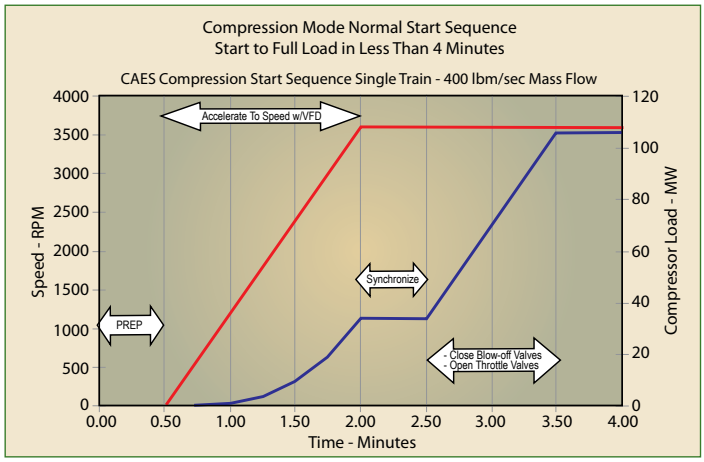


FIGURE 2: Compression mode normal start sequence

Dubbed ***SMART***CAES™ equipment and services, this enhanced offering is more than a name; it's a reflection of Dresser-Rand's unique qualification to deliver the total integrated rotating equipment system—a "one-stop" CAES solution. This solution includes not only the rotating equipment, but all ancillary services as well—the heat exchange equipment, pollution abatement system, and the plant controls—complete with performance guarantees (both compression and power generation modes).

Over the years, related research and development from other Dresser-Rand products have been incorporated into our CAES offering (e.g., DATUM® compressor technology enhancements), and these ever-improving technologies have put CAES at the "head of its class" on every relevant subject.

SMART ON TECHNOLOGY

Technological advancements achieved since first introducing the CAES design for the McIntosh facility bring a range of benefits to Dresser-Rand's ***SMART***CAES equipment, including operating flexibility, increased power output, reduced fuel and air consumption, improved compressor efficiency, noise reduction, and improved recuperator design.

Operating flexibility—*SMART*CAES equipment offers shorter startup times to achieve rated output in power generation mode, higher load ramping rates in power generation mode, faster compression start-up times, and faster transition between compression and power generation modes.

In power generation mode, the system is designed to start-up in less than 10 minutes to ramp output up to the rated 135 MW. Once synchronized, any output from 15 to 100 percent of rated load can be sustained indefinitely. Within this range, output may be ramped up or down at 20 percent of rated load per minute, or 27 MW per minute.

A variable speed drive system provides for rapid compression starts requiring less than 3.5 minutes. Once air is flowing to storage, the compressors may be turned down to any load between 65 and 100 percent of rated power, using variable inlet guide vanes, at a rate of 35 percent per minute (see figures 1 and 2).

For single train systems using a combination motor-generator, the variable frequency drive (VFD) system can be used to speed up the transitions between power generation and compression modes. Transitioning from power generation to compression can be achieved in five minutes, while adjusting from compression to power generation requires about 13 minutes. Multiple train systems, with separate motors for compression and generators for power production, eliminate mode transition time. The maximum transition time equals startup time in the desired mode.

Power output—The output of ***SMART***CAES turbo expanders was increased from 110 MW to 135 MW. Combining modern analytical techniques and upgraded materials, the calculated safety factors for both the high-pressure and low-pressure turbines' flowpaths remain virtually unchanged, despite a total output increase exceeding 20 percent.

Fuel and air consumption—Turbine and system enhancements such as better recuperator effectiveness result in a two percent heat rate improvement, coupled with a 1.2 percent reduction in specific air consumption (SAC), across the design operating range from 20 MW to 135 MW. The heat

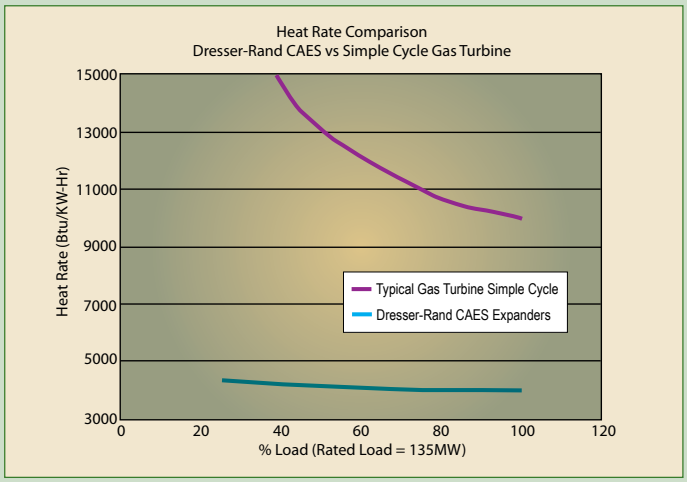


FIGURE 3: Heat rate comparison

rate of the Dresser-Rand ***SMART***CAES expanders is low and flat over a wide range of turndown from 100 percent load to 25 percent load because the expanders operate independent of the air compressors (see figure 3).

Compressor efficiency—Dresser-Rand's DATUM centrifugal compressor technology, more advanced axial compressor flowpath aerodynamics and careful design of the intercooled compression cycle all provide significant improvements in overall efficiency. Depending on final parameters, overall compression train flange-to-flange polytropic efficiency is in the mid-80 percent range in terms of energy consumption. The efficiency of the Power South CAES compressor train installed and operating in McIntosh is in the low 80 percent range (approximately three percent lower than Dresser-Rand's current CAES offering).

Noise reduction—Our patented noise reduction technology (D-R® duct resonator array) can achieve up to a 10 dB reduction in noise levels compared to centrifugal compressors that do not utilize this acoustic technology.

Recuperator design—The exhaust recuperator is a simpler design, with 85 percent heat transfer effectiveness compared to 75 percent in the earlier design. Strategically placed rows of stainless steel tubes avoid corrosion and exfoliation problems, and the entire recuperator is designed to operate at maximum air storage pressure, eliminating the cost and maintenance of pressure reducing valves. This change also makes sliding pressure cycles feasible where advantageous.

SMART ON THE ENVIRONMENT

The technological improvements to ***SMART***CAES equipment and services offer emission control options capable of meeting all current regulatory requirements for NO_x and CO limits. With features that can meet current emissions requirements, ***SMART***CAES equipment can do its part to reduce the buildup of greenhouse gases in the atmosphere and combat climate change.

A simple diffusion flame combustor with H_2O injection for primary NO_x control, coupled with an exhaust selective catalytic reduction system for final NO_x control, provides stable operation at high turndown ratios. It's possible to achieve final exhaust emission levels of 2 ppm NO_x and 2 ppm CO, corrected to 15 percent O_2. This means, depending on the operating profile, many potential CAES sites would fall under small-source emission limit rules. In addition, the VFD system reduces the compression start time, eliminating expander emissions from compression starts.

When used in conjunction with renewable energy such as wind or solar, ***SMART***CAES equipment has one-third the emissions of a conventional gas turbine.

SMART ON BUSINESS

The world's increasing focus on cleaner, greener energy use presents Dresser-Rand with an ideal opportunity to successfully integrate our CAES technology into new markets.

We recently secured a patent for a concept to combine a conventional CAES facility with a sub-sea piping and compressed air storage system. Such a structure could bring CAES technology to a range of coastal locations that represent nearly 80 percent of the world's demand for electricity.

The growing popularity of wind and solar energy could also spur interest in ***SMART***CAES solutions. Wind farms typically generate more electricity at night, when there's already a surplus, and the ability to "bottle" electric energy for daytime use is an attractive option. Within the solar market, electricity from photo-voltaic farms in sunny regions could be transmitted to facilities that use ***SMART***CAES equipment in other areas, where turbines would generate electricity year-round.

The world would benefit from increased use of renewable energy sources, such as wind and solar, however, a common reality is that they are inherently intermittent and to some degree unreliable. ***SMART***CAES equipment provides an excellent tool for "smart grid" management by having excellent load following capability, helping base load assets to be more efficiently utilized during off-peak times, and by being able to provide ancillary services such as VAR support, regulation and reserve.

The dynamics of the worldwide energy market are changing, and ***SMART***CAES solutions are one example of how Dresser-Rand is repositioning its offerings to address global needs. Renewable energy sources can benefit from the bulk energy storage capabilities that ***SMART***CAES equipment offers. ***SMART***CAES equipment is also complementary to energy conservation and development efforts associated with the "smart grid," giving utility operators the means to run their base load plants more efficiently.

Considering the careful research, advancements and efficiencies surrounding ***SMART***CAES equipment and services, its potential benefits are an obvious choice for creating an efficient power generation system.

For a complete list of products and services, visit **www.dresser-rand.com** or contact the following:

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