Title of Innovation:
High-Speed Large-Area Fusion Cladding

Nominee(s)
MesoCoat Inc.
Andrew Sherman, CTO, MesoCoat Inc.

Category:
Coatings and Linings

Dates of Innovation Development:
Jan 2010 – April 2013

Web site:
http://mesocoat.com/

Summary Description:
CermaClad™ is a unique metal coating/cladding process that uses a very high intensity light source to fuse various anti-corrosion and anti-wear protective materials onto metal substrates at 40X higher production rate, with better metallurgical and mechanical properties to provide longer life, and at 20% cheaper costs compared to current technologies such as laser cladding and weld overlay. CermaClad technology uses a high intensity arc lamp (mini-sun) which can heat spot up to 1,000,000°C and can melt, fuse, and metallurgically bond any material known to man onto metal substrates to protect the metal from corrosion, wear, erosion, heat, etc. With this technology, you can paint the world in stainless steel, at costs competitive with epoxies and paints.
CermaClad is the only technology that can melt and fuse titanium and other dissimilar metals onto steel in thicknesses ranging from 0.1mm to 15mm. CermaClad is also the only technology that enables deposition of 100µ thin metallurgical cladding of almost any corrosion- and wear-resistant material with minimal dilution, minimal porosity, and no damage to the substrate. This practically enables conversion of all carbon steel pipes and components to alloy pipes and components, by depositing a thin layer onto the inside and outside of pipes and components. By applying thinner metallurgical cladding, MesoCoat can significantly bring down the cost of cladding and thus compete with epoxies and paints in applications such as transmission pipeline coatings, shipbuilding, infrastructure, etc. – thereby expanding the applications and potential outreach of metal cladding.
Full Description:

How does the innovation work?

If you have ever burnt a bug or a piece of paper with a magnifying glass by focusing sun rays onto the piece of paper or a bug – you know how the technology works. CermaClad in essence, is a sun captured inside a reflector, which reflects very high intensity spectrum of heat onto the desired surface/area. So, you apply the corrosion and wear resistant material as a paste on the base metal that you need to protect, then you just scan the lamp over it, and within seconds the lamp melts, fuses, and metallurgically clads layer of corrosion and wear resistant material on top of the base metal.

CermaClad™ is a scalable, high-rate surface cladding/coating process that rapidly produces pinhole-free, smooth coatings and is primarily designed for applications where productivity and cost are important process-adoption criteria. This process uses light emitted from a High Density Infrared (HDIR) lamp (Fig. 2), which is concentrated into a line focus at 500-3000W/cm².

![Figure 2: The spectrum generated by the HDIR arc lamp is similar to the spectrum generated by the sun.](image)

The arc lamp consists of two electrodes separated by gas and, when charged, the gas turns into plasma. Argon gas swirls within a glass tube sealed by two electrodes on each side. When a strong arc of electricity travels between the electrodes, it strikes the argon atoms, generating a radiant intense heat similar to the sun. To keep the lamp cool, jets of highly-pressurized deionized water moves around the glass tube’s inner wall. The lamp takes the arc’s radiant energy and directs it to whatever material is below the lamp. Thus CermaClad™ in essence, is a sun captured inside a reflector, which reflects very high intensity spectrum of heat onto the desired surface/area. Because the process is area-based, thermal gradients in the cladding are minimized and dilution with base metal and weld solidification/liquation cracking are greatly reduced or eliminated. Chemical composition of SS316L coatings (as applied and after different levels of grinding) fused by this process is presented in Table 1.
Table 1: Chemical Compositions of the 2mm Thick SS316L Coatings Fused by HDIR Method (as Fused and at Different Levels of Grinding)

<table>
<thead>
<tr>
<th>Coating thickness (µm)</th>
<th>Fe</th>
<th>Cr</th>
<th>Mn</th>
<th>Ni</th>
<th>Mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition of SS316L powder (Wt %)</td>
<td>NA</td>
<td>68.88</td>
<td>16.6</td>
<td>1.3</td>
<td>10.2</td>
</tr>
<tr>
<td>Average Composition of coating (as applied) (Wt %)</td>
<td>1,900</td>
<td>68.8</td>
<td>17.625</td>
<td>1.275</td>
<td>8.9</td>
</tr>
<tr>
<td>Average Composition of coating (after 1st grinding) (Wt%)</td>
<td>420</td>
<td>74.44</td>
<td>13.27</td>
<td>1.19</td>
<td>9.38</td>
</tr>
<tr>
<td>Average Composition of coating (after 2nd grinding) (Wt%)</td>
<td>115</td>
<td>75.83</td>
<td>12.64</td>
<td>1.07</td>
<td>8.88</td>
</tr>
</tbody>
</table>

The original SS316L composition is retained in the as applied coating and there was no dilution of iron from the base material. Furthermore, even at very low thickness of the coating (115µm after grinding), there was very low Fe dilution and the Cr content was always around 13%, which was very beneficial for improving the corrosion resistance. Low dilution of the cladding with the base metal can be attributed to the limited Marangoni convective mixing during the cladding process. Thus thin coatings can be applied by the CermaClad™ process without affecting the chemistry. The spectrum of this broadband, non-coherent light source is represented in Fig. 3 [http://www.mattson.com/vortekarclamp.asp]. The lamp is designed to emit roughly 80% of its energy in the infrared spectrum, just over 18% is emitted in the visible light range, and only 1-2% is in the ultraviolet [Sherman, 2013].

The CermaClad™ application process produces smooth surfaces with less dissolution of the base material, highly refined grain size, and stronger metallurgical bond (with unprecedented
durability and resiliency). Bond shear strengths of coatings fused by the CermaClad™ technology were consistently reported to be above 30,000 psi through independent testing, which is 50% higher than API5LD standards requirements for metallurgically clad pipe (20,000-24,000 psi typical of roll-clad product, API specifies 20,000 psi shear).

CermaClad’s uniform fusion process is capable of controlling the phase and microstructure by controlling heat input. The substrate surface is prepared by common cleaning/grit-blasting methods, and CermaClad™ engineered precursors are applied onto the substrate material (base metal) by slurry deposition. After application, the HDIR lamp is rapidly passed over the cladding precursor, melting it, and thus bonding the cladding/coating to the base metal.

This process offers two additional benefits:

1. The overall system temperature of the system is controlled and only sufficient heat is provided to melt the cladding material. The substrate metal temperature remains low (although high enough to get metallurgical bonding), significantly minimizing mixing at the cladding/substrate interface and phase changes within the substrate.
2. With this process, it is possible to deposit a thin layer (between 0.1mm – 1mm) of cladding material, which reduces the material cost. Since the energy consumption is less compared to other similar processes, the CermaClad™ process encourages green manufacturing.

CermaClad™ has been used to fuse a uniform layer of Inconel 625, Inconel 825, stainless steel, metallic glass, copper and aluminum to metal surfaces. High melting point materials, such as Tungsten (Melting Point [M.P.] of 3,422°C), Molybdenum (M.P. of 2,623°C) and Titanium (M.P. of 1,668°C) have also been fused to the base materials by this process. The lamp technology has been used to fuse ceramics and composites too.

**When and how was the innovation developed?**

The development of this technology began in early 1996 at Oak Ridge National Lab (ORNL), when scientists at ORNL thought of using the ‘High Density Infrared’ (HDIR) arc lamp manufactured by Vortek, Inc. of Canada for thermal processing of functional materials, which was initially being used in the semiconductor processing industry. ORNL continued developing the technology for applying a variety of corrosion and wear resistant materials on samples and understanding the process, flow, metallurgy, control over temperature and chemistry as they continued their research. In 2008, MesoCoat Inc. approached ORNL for licensing this technology with the intention of using this technology to apply their patented nanocomposite materials on large-areas such as ship decks for a project sponsored by the U.S. Navy. MesoCoat realized the potential of this technology and exclusively licensed the technology from ORNL in 2010. Since then, MesoCoat has developed, demonstrated, and qualified variety of material with cladding thickness ranging from 100 microns to 15 mm for a variety of applications. In the past 3
years, MesoCoat has built its expertise in process control, metallurgy, material science, scalability, and reducing the footprint of the cladding system which was as big as a 4 feet cube to one that can go inside pipes as small as 7 inches in internal diameter. This technology has unlimited potential since it has no limitation on the materials that can be fused and can basically fuse any metal known to man on metal substrates for corrosion, wear, erosion, insulation, conduction or any other application. MesoCoat’s R&D activities are now focused on such niches that give them a competitive advantage over any other process.

How or why is the innovation unique?

CermaClad™ represents a revolutionary advancement in cladding technology because it can produce an exceptional product at a fraction of the cost and manufacturing time of competing technologies. The unique application of a high-intensity plasma arc lamp to cladding materials generates a strong metallurgical bond at the interface with the base metal substrate, producing cladding that can withstand extreme temperature pressures and resist corrosion and wear. The CermaClad™ process also improves processing times and maintains the structural integrity of base metal by limiting the penetration depth of the thermally affected zone during the cladding process. In short, it is simply a cheaper, better, and faster alternative to its competitors. Figure 5 illustrates the different steps involved in the pipe cladding process while Fig. 6 shows the arc lamp cladding the inside of a pipe.
CermaClad™ arc lamp can rapidly heat a spot up to 1,000,000°C and there is no limitation in terms of the material or thicknesses that can be clad to the substrate, without causing any damage to the substrate.

VALUE PROPOSITION:

Performance:
- Easy to bend, reel, inspect, and install compared to mechanically lined pipe
- Significantly lower amount of weld area compared to metallurgically clad plate to pipe
- High productivity manufacturing process ensures on-time delivery and shorter lead time
- True metallurgical bond, > 30,000 psi
- Lower corrosion and wear rate compared to competing technologies
- Significantly lower dilution and porosity
- Minimal heat input to the substrate
Cost:
- Allows application of very thin metallurgical clad layer with minimal dilution leading to massive cost savings
- High productivity manufacturing process ensures project costs are significantly lowered
- Low capital investment enables setting-up regional facilities to serve local demand

Time:
- 15-100X faster than weld/laser cladding, lowers, lead time by 75-80%
- Coverage of 75-580 sq.ft./hour with a single system
- Matches line speed of steel mills, thus avoiding any delay in the project schedule and scope

What type of corrosion problem does the innovation address?

Cladding refers to a process where a metal, corrosion resistant alloy or composite (the cladding material) is bonded electrically, mechanically or through some other high pressure and temperature process onto another dissimilar metal (the substrate) to enhance its durability, strength or appearance. The majority of clad products made today uses carbon steel as the substrate and aluminum, nickel, nickel alloys, copper, copper alloys and stainless steel as the clad materials to be bonded. Typically, the purpose of the clad is to protect the underlying steel substrate from the environment it resides in.

The International Energy Agency estimates that more than 70% of the remaining oil and gas reserves are highly corrosive [http://www.genoil.ca/main-about-us.html] and an increasing share of global oil and gas production is now offshore. To explore these corrosive reserves and especially the high-pressure high-temperature reserves found offshore, there is a need for pipes and components that can withstand the assault of extremely corrosive constituents present in these reserves.
Until the early 1990s, offshore exploration and drilling in deepwater areas was considered an economically unattractive option for the production of hydrocarbons from offshore reserves due to substantially higher development costs of drilling, the lack of heavy-duty equipment, technological limitations, and high project risks making it commercially unviable. However, with recent advancements in offshore drilling technology, offshore rigs, and vessels have helped exploration and production companies to venture into deepwater and ultra-deepwater basins. Even governments across different countries have been encouraging deepwater and ultra-deepwater E&P activity through favorable policies, taxation systems, and concessions in order to achieve maximum possible energy self-reliance. Deepwater activity is expected to grow substantially in the future, and is likely to witness aggressive steps by E&P companies worldwide seeking to drill for new hydrocarbon reserves in deeper waters.

Deepwater oil and gas production involves hydrocarbons, produced water (brine), carbon dioxide (CO₂), hydrogen sulfide (H₂S), and other chemicals. Under high pressures and temperatures, brine can form acidic mixtures that cause general corrosion and pitting of pipes and solid mineral deposits (scale) that inhibit flow. In ultra-deepwater wells—those wells located in water depths >7,500 ft (2,286 m)—temperatures and pressures can be extreme, with temperatures up to 250°C and pressures of 25,000 psi (172 MPa) or higher, and produced water can have higher salinity levels leading to formation of different types of scale as well as accelerate corrosion and initiate stress corrosion cracking (SCC).

The global oil and gas capital expenditure (CapEx) is expected to increase from $1,036 billion in 2012 to $1,201 billion in 2013, registering a growth of 15.9%. The trend of increasing capital expenditure is expected to continue for the foreseeable future, especially driven by reserves that are deeper and farther away from the shore. Infield Systems Deepwater and Ultra-deepwater Market Report states that the largest proportion of deepwater investment to be directed towards pipeline installations; comprising 39% of total global deepwater expenditure - and clad pipes would constitute a healthy share of this offshore pipeline investment.

Oil and gas companies have been exploring in progressively deeper fields. For example, Transocean Ltd recently stated that it drilled the deepest well in its company’s history, at 10,385 feet underwater. Drilling in deeper waters, along with the discoveries of new offshore oil and gas fields around the world, has led to strong increases in offshore production equipment. Noble Corporation stated in its FY12 earnings conference call that oil and gas E&P companies announced 52 oil and gas field discoveries that were at least 4,000 feet underwater, breaking the previous record by 40%.
Eighteen of these fields were at least 7,000 feet underwater and nine of these fields were at least 8,000 feet underwater. These numbers are indicative of the trend toward producing oil and gas in deeper offshore fields. It is expected that this trend will continue, which will create the need for increases in both the quality and quantity of clad pipe.

In addition, the high CO₂ content witnessed in the reserves in the Asia-Pacific and MENA regions, and high H₂S content in Gulf of Mexico, Brazil, and West Africa which when coupled with higher pressure and higher temperature of these deepwater reserves, make corrosion not just a concern but a challenge, a substantial challenge. To encounter such corrosive assault, it has become imperative to use corrosion-resistant clad pipes which perform the role of solid CRA pipes but at 1/5th cost thus making several of these challenging reserves economically viable.

The past few years have also seen rapid adoption of some of the unconventional and extremely challenging resources such as oil sands, shale, pre-salts, along with increased adoption of enhanced oil and gas recovery processes. Significant technical advancements have enabled us to not only explore some of these resources that have been known for decades, but also enabled us to make exploration and production from these reserves highly economical thus propelling massive adoption and growth. However, all these unconventional resources pose a serious challenge in corrosion and wear. For example, hydro-transportation of very abrasive slurry from the mining site to the processing facility leads to such massive wear that the pipes carrying these abrasive slurries have to be rotated 1/3rd every 3-4 months and then replaced every 15-18 months; leading to massive maintenance, downtime, and repair costs. In 2011, the estimated cost of downtime and losses to Oil Sands industry was estimated to be $11 billion; almost 40% of these losses can be attributed to maintenance, repair, and replacement of pipes. It is expected that the demand for clad pipes is expected to grow by 3-5X in the Canadian oil sands market spearheaded by 3X increase in production of oil sands through the mining process. On the other hand enhanced oil recovery processes involves injecting corrosive chemicals and CO₂ at high pressures which leads to accelerated corrosion. Also many of the larger shale reserves with tighter formation have higher levels of sulfur, creating hydrogen sulfide (H₂S), a corrosive gas. The increasing adoption of unconventional energy sources has led to operations in very challenging and corrosive environments, which further substantiates the need for corrosion- and wear-resistant clad pipes and components to enable safer and efficient production from these reserves.

**What is the need that sparked the development of the innovation?**

Metal cladding has seen little to no innovation over the past 5-6 decades. Very low productivity weld overlay technology was invented in early 20th century; and the lower productivity of the weld overlay technology led to invention of higher productivity technologies like roll-bonding and mechanical cladding in the mid-20th century. Since then, there has been no innovation in the
metal cladding space. There are several limitations with the current technologies; which include, low productivity, difficulty in inspection and installation, higher risks, and inability to deploy the technology in thick-walled and large-diameter pipes. The limitations of current technologies coupled with the technologies reaching their functional limit for performance lead MesoCoat to develop a solution to address this market and this large and growing technical limitation.

**Are there technological challenges or limitations that the innovation overcomes?**

Clad pipe is typically produced by cladding a low-cost carbon steel substrate with a corrosion-resistant stainless steel or nickel alloy, which costs a fraction of using a more expensive solid steel alloy for the entire product. While cladding carbon steel pipes is cheaper than using solid stainless steel alloy, the conventional technologies used to produce clad pipe have several limitations. Metallurgical clad pipes are normally made using roll-bonded clad plate which is then bent and welded to form a pipe. Even though this is a higher productivity process, it involves a lot of welded area especially in pipes larger than 14” diameter which require spiral welding since the plates are not large enough to produce longitudinally welded pipes. Failure of weld is the single most common reason for pipeline leaks. The mechanically lined (bi-metal) pipe that now makes up a significant portion of the clad pipe market is lower in cost than metallurgically clad pipe. However, this approach provides only a marginal contact between the inner and outer pipe, leading to a higher possibility of buckling, wrinkling and disbonding under stress, bending, during reeling, and application of external coatings on these pipes. These pipes also raise concerns with respect to uniformity and reliability; and the air gap, coupled with the mixture of materials, leads to challenges in Non-Destructive Testing (NDT) inspection that contribute to risks associated with reliability.

There are also other techniques for manufacturing clad pipes such as weld overlay and co-extrusion. In weld overlay, the clad metal layer is deposited on the base metal using arc-welding-type processes while a composite billet (outer surface: carbon steel, inner surface: CRA) is extruded to form clad pipes in co-extrusion. However these technologies have been used on a very limited scale due to several quality and productivity limitations.

There is huge need for clad pipes as more deepwater corrosive reserves come into production, and the current solutions not only have several limitations but also have limited availability leading to an increasing large demand supply gap.

CermaClad™ clad pipes due to its strong metallurgical bond and mechanical properties are easier to inspect, bend, reel, and install unlike the mechanically lined pipes; provide a seamless cladding unlike the roll bonded plate to pipe alternative; and are 40-100X higher in productivity compared to weld overlay and laser cladding. More importantly, there is huge demand for thick-walled clad pipes in Gulf of Mexico and Brazil, and a massive requirement for large-diameter clad pipes in the Asia-Pacific and Middle East and North Africa (MENA) regions. The
mechanically lined pipe and roll bonded plate to pipe alternatives are not ideal for thick-walled and large-diameter clad pipes due to several quality and mechanical limitations. However, CermaClad™ clad pipes provide the ideal solution for thick-walled and large-diameter clad pipes.

**What are the potential applications of the innovation?**

Imagine the possibilities with steel that lasts 3-6X longer - It will lead to a paradigm shift in the metal asset protection and life extension. Oil pipelines that do not rupture/fail due to corrosion, bridges and infrastructure that lasts 80-100 years, ships that last its design life without any repairs/maintenance related to corrosion, heat exchangers and tubes that can be used for ultrasupercritical boilers which provide higher efficiency energy, great amount of reduction in energy consumption and carbon emission since you do not have to replace steel for 3X its current life – These are just some examples, just imagine the possibilities with steel that lasts 3-6X longer.

The primary application of this technology is to manufacture Corrosion and Wear resistant metallurgically clad pipes for a wide range of applications like risers and flow lines in both onshore and offshore Oil and Gas production, transportation, processing, and refining; hydro-transportation and tailings pipe for Oil Sands transportation and processing; Ore and other slurry lines for Mining; and flow lines for processing and production in various industries. The secondary application of the CermaClad technology is to manufacture Corrosion and Wear resistant metallurgically clad plates used in mining and processing applications; clad plates and components for ship decks, ballast and cargo tanks; and for fabricating pressures vessels, reactors, tanks, rolls, heat exchangers, valves, separators, and other components for Oil and Gas, Mining, Power generation, Nuclear, Desalination, Cement, Steel, Marine, Paper and Pulp, Hydrometallurgy, and other industries.

A huge gap in supply and demand existed for metallurgically clad steel for a variety of applications, and especially metallurgically clad pipe for deepwater Oil and Gas production and transportation. The current technologies weld overlay and laser cladding; have existed over many decades with little to no innovation to improve productivity to meet this huge demand v/s supply gap. Also, the high costs associated with the metallurgically clad products did not help wider adoption. There has been a compelling need for a cladding technology that can shoot-up productivity by at least 10-20 times, offer better metallurgical and surface properties that eventually provide better corrosion and wear resistance leading to longer life, and reduce the high costs associated with metallurgically clad products. So, the gap boiled down to time (demand v/s supply), cost, and performance. The shortcomings of metallurgically clad pipes forced Oil and Gas companies to select lower quality mechanically lines pipe and roll-bonded plate-to-pipe options since they were available in bulk quantities and in shorter lead times. Mechanical Lined pipe have severe buckling, reeling, and bonding issues whereas the roll-
bonded pipes are not seamless and have a lot of weld which increases the risk of failure to a great extent. CermaClad is a disruptive innovation that allows end users to use metallurgically clad products that have 75-80% reduced lead time due to 15-100X higher production rate, at 20% cheaper costs due to a great amount of reduction in operating expenses and production time, and longer life due to better surface and metallurgical properties.

**CermaClad Addressable Markets:**

- Primary Addressable Market
  - Immediate: $1.8 billion (clad pipe)
  - Current: $3.8 billion
  - 2015: $7.6 billion
  - New Markets: $20+ billion
- Oil and Gas ($1.8 billion)
  - Pipes, Risers, Flowlines
- Oil Sands ($225 million)
  - Slurry lines, Hydro-transportation and tailings pipe, wear plates
- Mining ($1+ billion)
  - Slurry lines, wear plates, screens, beds
- Nuclear and Energy Generation ($1+ billion)
  - Heat Exchangers, Pressure Vessels, Tanks, Reactors
- Shipbuilding ($10+ billion)
  - Ballast and Cargo tanks, Ship Decks
- Infrastructure ($10+ billion)
  - Rebar, Structures, Components

**How does the innovation provide an improvement over existing methods, techniques, and technologies?**

The adoption of clad pipes in large quantities began in early 1990’s and to date several hundred kilometers of clad pipes have been used in both onshore and offshore applications. Mechanically lined (bi-metal) pipes and pipes manufactured using roll-bonded clad plates are the two most widely used clad pipe solutions.

The manufacturing of mechanically lined pipe involves the insertion and dry/wet hydraulic expansion of a corrosion resistant alloy (CRA) pipe inside higher strength carbon steel outer pipe. Whereas, the metallurgical clad pipes are made from roll-bonded clad plates. The clad metal and base metal are bonded together during the hot rolling operation in which the metal slab is converted to plate. These plates are then either welded longitudinally and/or spirally depending upon the size of pipe and process preferred by the manufacturer to form clad pipes.
As discussed earlier, there are also other techniques for manufacturing clad pipes such as weld overlay where the clad metal layer is deposited on the base metal using arc-welding-type processes; and co-extrusion where a composite billet where the outer surface is carbon steel and the inner surface is corrosion resistant alloy, and this composite billet is then extruded to form clad pipes - however these technologies have been used on a very limited scale due to several quality and productivity limitations.

Metallurgical clad pipes are normally made using roll-bonded clad plate which is then bent and welded to form a pipe; though a higher productivity process, it involves a lot of welded area especially in pipes larger than 14” diameter which require spiral welding since the plates are not large enough to produce longitudinally welded pipes – failure of weld is the single most common reason for pipeline leaks. The mechanically lined (bi-metal) pipe that now makes up a significant portion of the clad pipe market is lower in cost than metallurgically clad pipe, but provides only marginal contact between the inner and outer pipe, leading to a higher possibility of buckling, wrinkling and disbonding under stress, bending, during reeling, and application of external coatings on these pipes. These pipes also raise concerns with respect to uniformity and reliability; and the air gap, coupled with the mixture of materials, leads to challenges in NDT (non-destructive testing) inspections that contribute to risks associated with reliability. There is huge need for clad pipes as more deepwater corrosive reserves come into production, and the current solutions not only have several limitations but also limited in availability creating an increasing large demand supply gap.

Clad pipes manufactured using the CermaClad™ technology due to its strong metallurgical bond and mechanical properties are easier to inspect, bend, reel, and install unlike the mechanically lined pipes; and provide a seamless cladding unlike the roll bonded plate to pipe alternative. More importantly, there is huge demand for thick-walled clad pipes in Gulf of Mexico and Brazil, and a massive requirement for large-diameter clad pipes in the Asia-Pacific and MENA regions – the mechanically lined pipe and roll bonded plate to pipe alternatives are not ideal for thick-walled and large-diameter clad pipes due to several quality and mechanical limitations. HDIR fusion clad pipes provide the ideal solution for thick-walled and large-diameter clad pipes.

The primary value propositions of this technology are presented below:

**Performance:**
- Easy to bend, reel, inspect, and install compared to mechanically lined pipe
- Significantly lower amount of weld area compared to metallurgically clad plate to pipe
- High productivity manufacturing process ensures on-time delivery and shorter lead time
- True metallurgical bond, > 30,000 psi
- Lower corrosion and wear rate compared to competing technologies
- Significantly lower dilution and porosity
- Minimal heat input to the substrate
Cost:
- Allows application of very thin metallurgical clad layer with minimal dilution leading to massive cost savings
- High productivity manufacturing process ensures project costs are significantly lowered
- Low capital investment enables setting-up regional facilities to serve local demand

Time:
- 15-100X faster than weld/laser cladding, lowers, lead time by 75-80%
- Coverage of 75-580 sq.ft./hour with a single system
- Matches line speed of steel mills, thus avoiding any delay in the project schedule and scope

What type of impact does the innovation have on the industry/industries it serves?

CermaClad represents a revolutionary advancement in cladding technology because it can produce an exceptional product at a fraction of the cost and manufacturing time of competing technologies. CermaClad changes metallurgical cladding from being merely a ‘Preferred Option’ to the ‘Most Viable Option’ with the highest benefit/cost ratio at the lowest risk for some of the most extreme environments where clad steel or alloy steel are considered as the best alternative.

Apart from the several value propositions highlighted in the preceding sections; mentioned below are some additional benefits and value proposition:

Environmental Benefits
- MesoCoat's CermaClad™ technology provides the best metallurgical cladding on steel with corrosion and wear resistant materials that provide longer design life for steel plates, pipes, bars and components and, thereby, reducing the environmental impact to a great extent.
- In this innovation, a high-intensity light source provides fast heating and high-quench rates needed to producing nanocomposite and amorphous metal coatings, eliminating the liquid and solid waste streams of alternate processes (such as galvanizing) while providing metallurgically-bonded metal coatings.
- Building new resistant materials to extend the life of steel products through these advanced coatings by CermaClad™ will cut back on the need for new steel production to replace those products, hence reducing carbon emissions from steel production.
- Metal cladding also eliminates the use of VOCs, like paints and epoxies and disposal of remaining epoxies/paint, is completely eliminated.
- This process is more environmentally friendly since pure metals are applied and fumes are not generated.
**Life Cycle Assessment (LCA)**

- The LCA (analysis of environmental impacts throughout all stages of the process) for this technology to use a focused, high-intensity light source to fuse Zn based coatings is discussed below with the corresponding stage of the cycle (raw materials, manufacturing process, distribution, use, and disposal) mentioned after each analysis point.
- Optical/light fusion is a “dry” method, generates very little liquid waste and is exempted from many EPA regulations. *(Disposal)*
- Optical fusion has very high energy conversion to heat/radiation (60-65% electrical conversion to radiant output, 35-40% efficiency to heat flux onto the substrate with reasonable reflectors) compared to combustion and laser (<6%) sources of heating and provides a very fast control response compared to other heating processes. Therefore, it’s a nearly universal adoption for semiconductor heat treatment. *(Manufacturing Process)*
- The combination of electrostatic spray (98% efficient) followed by optical fusion has materials yields approaching 100%. *(Raw Materials)*
- Optical fusion is 1-2 orders of magnitude faster than hot dip galvanizing application rates. *(Manufacturing Process)*
- Light fusion can be combined with HVOF for field installation (weld coating) and spot repairs prior to introduction of portable (field use) units for faster time to market in the future. *(Distribution and Use)*
- The use of corrosion resistant alloy/composite overlays provides a non-toxic, longer life alternative to toxic metal claddings, while being directly insertable into current mill product production lines. *(Manufacturing Process)*

Therefore, these factors make the proposed HDIR fusion solution a cheaper and environmentally friendly approach to produce coatings at a very fast rate.

**Does the innovation fill a technology gap? If so, please explain the technological need and how it was addressed prior to the development of the innovation.**

CermaClad clad pipes would enable economic and low-risk production from some of the most corrosive reserves across the globe. According to International Energy Agency, more than 70% of the reserves remaining in the world are highly corrosive (H2S, CO2) – and hence would require corrosion resistant pipes and components in large quantity. CermaClad™ pipes due to its strong metallurgical bond and mechanical properties are easier to inspect, bend, reel, and install unlike the mechanically lined pipes; and provide a seamless cladding unlike the roll bonded plate to pipe alternative. More importantly, there is huge demand for thick-walled clad pipes in Gulf of Mexico and Brazil, and a massive requirement for large-diameter clad pipes in the Asia-Pacific and MENA regions – the mechanically lined pipe and roll bonded plate to pipe alternatives are not ideal for thick-walled and large-diameter clad pipes due to several quality and mechanical
limitations. CermaClad™ clad pipes provide the ideal solution for thick-walled and large-diameter clad pipes.

Table 2: Comparison of the HDIR coating/cladding process to other conventional coating/cladding processes

<table>
<thead>
<tr>
<th>Process</th>
<th>Bonding</th>
<th>Process Cost</th>
<th>Productivity</th>
<th>Limitation(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weld Overlay</td>
<td>Metallurgical</td>
<td>Very high</td>
<td>10Kg/hr</td>
<td>Dilution, low productivity</td>
</tr>
<tr>
<td>Thermal Spray</td>
<td>Mechanical</td>
<td>High</td>
<td>5Kg/hr</td>
<td>Thickness, bond strength</td>
</tr>
<tr>
<td>Vapor Deposition</td>
<td>Metallurgical</td>
<td>High</td>
<td>0.1Kg/hr</td>
<td>Cost, thickness, low productivity</td>
</tr>
<tr>
<td>CermaClad™</td>
<td>Metallurgical</td>
<td>low</td>
<td>500Kg/hr</td>
<td>&gt;8” Diameter only</td>
</tr>
<tr>
<td>Pipe in Pipe</td>
<td>Mechanical</td>
<td>Very low</td>
<td>High</td>
<td>Bonding, inspection, installation, capital costs, thick-walled and large-diameter pipes</td>
</tr>
<tr>
<td>Roll-cladding</td>
<td>Metallurgical</td>
<td>low</td>
<td>High</td>
<td>Not seamless, large weld area, capital costs, thick-walled and large-diameter pipes</td>
</tr>
<tr>
<td>Co-extrusion</td>
<td>Metallurgical</td>
<td>Very low</td>
<td>High</td>
<td>uniformity of thickness, yield strength, capital costs</td>
</tr>
</tbody>
</table>

Has the innovation been tested in the laboratory or in the field? If so, please describe any tests or field demonstrations and the results that support the capability and feasibility of the innovation.

Table 3: Summary of the test results under the API-5LD and DNV-OS-F101 standards on Alloy 625 clad samples

<table>
<thead>
<tr>
<th>Test</th>
<th>Acceptance Criteria</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bend Test</td>
<td>No cracks longer than 1/8”</td>
<td>Pass</td>
</tr>
<tr>
<td>Tensile Test</td>
<td>&gt;65 ksi</td>
<td>67 ksi</td>
</tr>
<tr>
<td>Charpy Impact Test</td>
<td>&gt;40 J</td>
<td>406.7 J</td>
</tr>
<tr>
<td>Shear Test</td>
<td>20,000 psi</td>
<td>31,257 psi</td>
</tr>
<tr>
<td>Corrosion Test</td>
<td>Similar to Weld Overlay</td>
<td>Weld Overlay (177 mpy) Wrought Plate (7.8 mpy) CermaClad (10-30 mpy)</td>
</tr>
<tr>
<td>Hardness</td>
<td>Max 325 HV</td>
<td>300 HV (average range: 205-246)</td>
</tr>
<tr>
<td>Chemical composition</td>
<td>UNS 06625</td>
<td>Compliant, Fe&lt;2%</td>
</tr>
</tbody>
</table>

Independent testing at the largest risk management laboratory, Det Norske Veritas (DNV) sponsored by the company’s technology development partner, Petrobras S.A (NYSE: PBR), has confirmed that clad products manufactured using the HDIR fusion cladding process provides a
better product with 95% lower dilution, 50% higher metallurgical bond strength, and significantly higher mechanical integrity and toughness; compared to the defining API 5LD standard requirements for metallurgically bonded clad X65 pipe.

MesoCoat has also completed testing of its CermaClad wear resistant clad products with one of the largest oil sands producer in Canada, and CermaClad wear resistant samples showed 3X longer life compared to weld overlay samples using the same material.

**Is the innovation commercially available? If yes, how long has it been utilized? If not, what is the next step in making the innovation commercially available?**

MesoCoat has demonstrated cladding on smaller section of pipes, and is now in the final stage of demonstration and qualification of cladding for full-length (40 feet) pipe. The first CermaClad clad pipe manufacturing facility is now operational in Euclid, Ohio and the company expects to qualify full length clad pipes to the DNV-OF-F101 and API-5LD standards later this year, and then commence full-scale production. Figure 9 shows the new facility.

Figure 9: First full-length (40 feet) clad pipe manufacturing facility commissioned in April, 2013

MesoCoat is now setting-up large clad pipe manufacturing plants in Brazil and Indonesia to supply the highest quality metallurgical clad pipes for projects across the globe, as we see an increasing number of projects getting delayed due to lack of supply and lower quality of clad pipes. The very high productivity of the HDIR technology enables the company to set-up clad
pipe manufacturing facilities at a tenth of the cost of competing technologies; which allows the company to set-up multiple facilities across the globe to serve the regional market and fulfill the growing and critical local content requirement in South America, Indonesia, Africa, Middle East, and other regions - a trend that is expected to continue and grow over the foreseeable future. MesoCoat intends to have capability of producing up to 200 kms of 10” clad pipes in 2015, and then expects to add new clad pipe manufacturing facilities in Middle East, Mexico, Alberta, and Europe to produce more than 500 kms of 10” clad pipes to serve the rapidly growing clad pipe market across the globe.

Are you aware of other organizations that have introduced similar innovations? If so, how is this innovation different?

It is an absolutely new disruptive technology; no other company has tried using a HDIR arc lamp to fuse protective coatings on metals. CermaClad™ combines proprietary high-speed fusion cladding equipment that is faster, better, and more cost-competitive than current processes with proprietary corrosion- and wear-resistant alloy coating materials incorporating patented microstructural and compositional modifications that lead to industry-leading performance and life.

Are there any patents related to this work? If yes, please provide the patent title, number, and inventor.

MesoCoat own the patents for the CermaClad application process, final cladding parameters, material compositions, and the use of the high energy density infrared arc lamp to apply protective coatings and surface engineering; and we have an exclusive supply agreement with the only manufacturer of these high energy density infrared arc lamps. So, the intellectual property is water-tight with both US and global patents and the expertise gained over several years to control to process parameters, metallurgy, and material composition to apply an optimum cladding on metal substrates.

MesoCoat believes that additional Intellectual Property will be developed around specific applications, and specific equipment configurations which provide economic, productivity, and quality enhancements of the fusion applied coatings/claddings. When appropriate, MesoCoat will apply for additional patent protection. In the International market, MesoCoat will consider selectively licensing or franchising the technology to carefully-selected licensees, but maintains a strong preference to company-owned and controlled coating plants in order to maintain control over the IP and product quality. Mentioned below is a list of published and provisional patents related to this technology.
<table>
<thead>
<tr>
<th>No.</th>
<th>Title</th>
<th>Patent Number</th>
<th>Assignee</th>
<th>Licensed to</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rapid infrared heating of a surface</td>
<td>6174388 B1</td>
<td>Lockheed Martin Energy Research Corp., U.T. Battelle LLC, Oak Ridge, TN</td>
<td>MesoCoat Inc.</td>
</tr>
<tr>
<td>2</td>
<td>Abrasive particles with metallurgically bonded metal coatings</td>
<td>6540800 B2</td>
<td>Powdermet Inc.</td>
<td>MesoCoat Inc.</td>
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<tr>
<td>3</td>
<td>Method of producing fine coated tungsten carbide particles</td>
<td>6641918 B1</td>
<td>Powdermet Inc.</td>
<td>MesoCoat Inc.</td>
</tr>
<tr>
<td>4</td>
<td>Combined liquid phase and activated sintering of refractory metals</td>
<td>7041250 B2</td>
<td>Powdermet Inc.</td>
<td>MesoCoat Inc.</td>
</tr>
<tr>
<td>5</td>
<td>Pulse thermal processing of functional materials using directed plasma arc</td>
<td>7220936 B2</td>
<td>UT-Battelle, LLC, Oak Ridge, TN</td>
<td>MesoCoat Inc.</td>
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<tr>
<td>7</td>
<td>Heterogeneous composite bodies with isolated lenticular shaped cermet regions</td>
<td>7635515 B1</td>
<td>Powdermet Inc.</td>
<td>MesoCoat Inc.</td>
</tr>
<tr>
<td>8</td>
<td>Heterogeneous composite bodies with isolated lenticular shaped cermet regions</td>
<td>7681622 B2</td>
<td>Powdermet Inc.</td>
<td>MesoCoat Inc.</td>
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<tr>
<td>9</td>
<td>Coatings, Composition and method related to non-spalling low density hardface coatings</td>
<td>US2010/0203255A1</td>
<td>MesoCoat Inc.</td>
<td>N/A</td>
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<tr>
<td>10</td>
<td>Coatings, Composition and method related to non-spalling low density hardface coatings</td>
<td>N/A</td>
<td>MesoCoat Inc.</td>
<td>N/A</td>
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<tr>
<td>11</td>
<td>Article and method of manufacturing related to nanocomposite overlays</td>
<td>N/A</td>
<td>MesoCoat Inc.</td>
<td>N/A</td>
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<tr>
<td>12</td>
<td>Article and method of manufacturing related to nanocomposite overlays</td>
<td>US2010/0297432A1</td>
<td>MesoCoat Inc.</td>
<td>N/A</td>
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<tr>
<td>13</td>
<td>Method and Apparatus for forming clad metal products</td>
<td>61/451,114</td>
<td>MesoCoat Inc.</td>
<td>N/A</td>
</tr>
<tr>
<td>14</td>
<td>Thin Metal Coatings</td>
<td></td>
<td></td>
<td>MesoCoat Inc.</td>
</tr>
</tbody>
</table>
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    ▪ Metal Tank Manufacturing in the USA
    ▪ Mining, Oil & Gas Machinery Manufacturing in the USA
    ▪ Oil Drilling & Gas Extraction in the USA
    ▪ Oil Pipeline Transportation in the USA
    ▪ Pipeline Construction in the USA
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