AASHTO
AASHTO INNOVATION INITIATIVE

AASHTO Innovation Initiative

[Proposed] Nomination of Innovation Ready for Implementation

Sponsor

Nominations must be submitted by an AASHTO member DOT willing to help promote the innovation

1. Sponsoring DOT (State): Virginia

2. Name and Title: Kendal Walus, P.E. - State Structure and Bridge Engineer

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   State: Virginia

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3. Is the sponsoring State DOT willing to promote this innovation to other states by participating on a Lead States Team supported by the AASHTO Innovation Initiative? ☒ Yes ☐ No

Innovation Description (10 points)

The term "innovation" may include processes, products, techniques, procedures, and practices.

4. Name of the innovation:

Laser ablation coating removal (LACR) for highway bridge structural steel

5. Please describe the innovation. Describe how this innovation transforms your existing “state of play.”

Laser coating removal is an ablative process that can be applied to a variety of substrates, including metal. Laser ablation uses high-energy light pulses that are directed at a target to eject the surface layers of material. Laser energy is focused onto the surface and is absorbed into the coating, resulting in decomposition and removal of the coating and causing only a minimal increase in substrate temperature while providing a surface that is adequately prepared for the application of new coatings. The LACR process converts the existing coating material to a plasma, which is continuously pulled from the ablation site through suction (there is a vacuum shroud on the laser equipment that pulls the plasma and carries it through tubes to a filter, located remotely from the laser), resulting in extremely low levels of airborne toxicity in the vicinity of the laser ablation. This is illustrated in Figure 1.

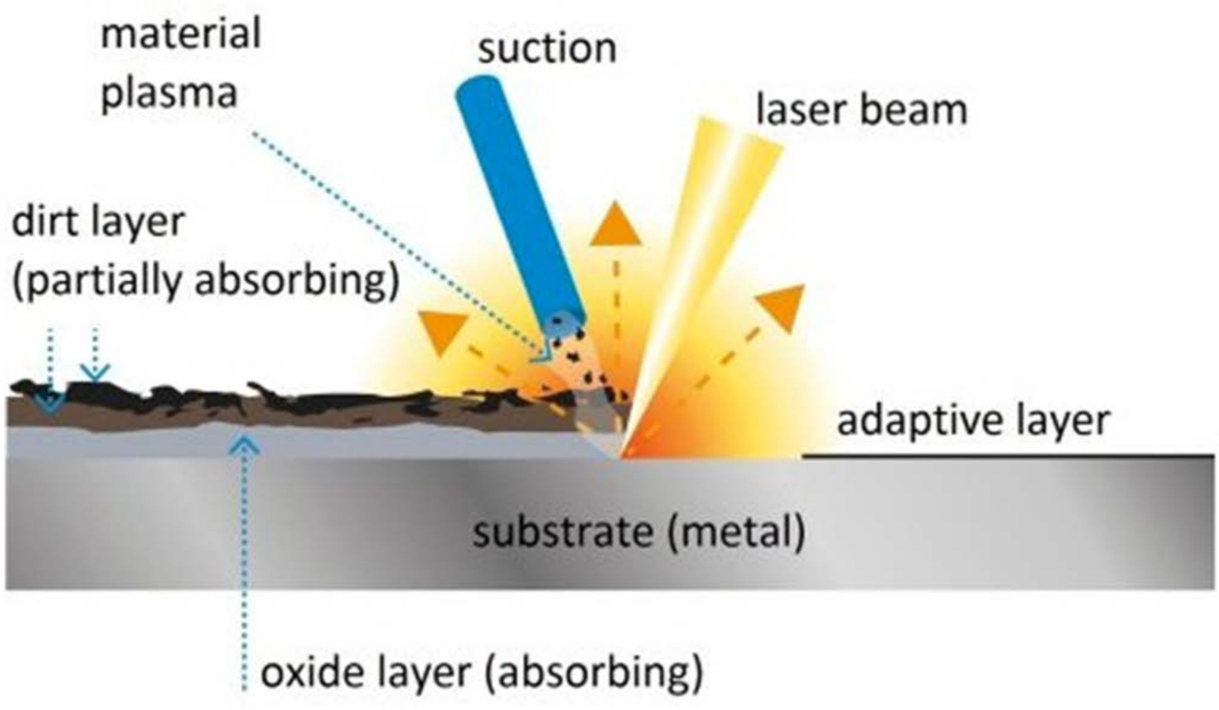

Figure 1. Illustration showing laser ablation coating removal cleaning a metal surface while adding no additional waste

Full implementation of lasers for coating removal could positively disrupt Virginia’s bridge preservation program by allowing the localized recoating of bridge girders rather than the recoating of entire bridges. This could lead to recoating activities on as many as 6 times as many bridges with the same budget. In Virginia, the vast majority of steel bridges that require recoating only need beam end or spot coating.

This is because leaking expansion joints accelerate coating damage near the beam ends, while the coatings on the remaining portions of the beams tend to remain intact. However, the economics of bridge recoating lead to recoating of the entire structure rather than just the beam ends. This is because the cost of containment is about the same whether we recoat an entire structure or just the beam ends. As a result, the cost of entire structure recoating is only nominally higher than beam end coating, leading us to our current practice of recoating entire structures in the vast majority of cases. These economic models are significantly different with LACR.

Laser ablation for coating removal provides an environmentally safe and effective method of removing coatings without using containment structures. Based on our studies and information received from other users, we believe that this process could allow Virginia to preserve more bridges while greatly reducing potential exposure for workers to hazardous materials such as lead.

Current applications range from art and sculpture cleaning and refurbishing, paint and graffiti removal, nuclear decontamination, and rust removal, to coating removal on aerospace and marine structures. Laser ablation coating removal (LACR) can effectively remove coatings from steel substrates. Laser cleaning has found uses for cleaning building facades, exteriors, and even sculptures and ornaments. The Philadelphia City Hall, US Capitol Building and Canadian Parliament building are examples of prominent landmarks that have been successfully cleaned using LACR technology.

Laser ablation coating removal (LACR) provides tremendous potential for highway bridges as a viable alternative to conventional coating removal methods such as abrasive blasting, chemical stripping, or power tool cleaning.

The advantages of LACR include elimination of containment structures, reduced waste generation, reduced employee exposure and selective coating removal.

The overwhelming majority of bridge deterioration in Virginia is caused by corrosion in steel reinforcement and steel beams/girders. The corrosion is primarily attributable to exposure to chloride-laden water that attacks bridge elements due to leaking expansion joints, which can be seen in Figure 2.

Figure 2: A common observation in the field is that salt-laden water leaking through the expansion joints in bridge decks leads to coating damage and corrosion-related section loss, which is located almost exclusively at the beam-ends

The analysis below compares the cost of coating the beam ends of a notional bridge with leaking deck expansion joints. The Option 1 calculation investigates the cost of using traditional zone coating with abrasive grit blasting, while Option 2 calculates the cost of performing the same work with LACR. Note that LACR permits 3' rather than the conventional 5'. 5' is normally used not for performance, but because this represents the practical lower limit for length of a containment area.

- **Notional Bridge**
    - Grade Separation
    - Secondary Route Crossing an Interstate Route
    - Five Simply Supported Spans
    - Four Beams per Span

- **Option 1:** Zone Coat the end five feet of each beam by conventional methods (based on average contract prices in Virginia)

  Cost = ($596.21/LF)(5 LF)(4 beams)(2 beam ends/beam)(5 spans) = $119,242 per bridge

- **Option 2:** Zone Coat end 3’ of each beam using LACR. Use production rates observed during field trial.

  Cost = ($126.33/LF)(3LF)(4 beams)(2 beam ends/beam)(5 spans) = $15,160 per bridge

  Basis for Option 2 Cost:
  - $52/hour loaded cost for bridge crew member
  - 6 man hours per beam end - laser removal
  - 1 hour per beam end to recoat
  - $364: Labor per beam end (7 hours @$52/hour)
  - $15 Materials
  - $379 Total Cost per beam end (= $15 + $364)
  - 3LF per beam end: Note that LACR permits 3’ rather than the conventional 5’. 5’is normally used not for performance, but because this represents the practical lower limit for length of a containment
  - $126.33 Cost per foot for LACR Recoating of 3' Beam End (=$379/3’)

With an approximate saving of $104,000 per bridge ($119k - $15k = 104k), these calculations indicate that the cost of purchasing the equipment may be recovered by zone coating six bridges with LACR.

6. If appropriate, please attach photographs, diagrams, or other images illustrating the appearance or functionality of the innovation (if electronic, please provide a separate file).

Figure 3: Handheld Laser in Use

Figure 4: Photograph showing optic head and end-effector. Note the power feed and vacuum hose at the rear of the unit

Figure 5: Filtration Cabinet - Located in Remote Area. Airborne contaminants are vacuumed from the LACR site to the HEPA filter, greatly reducing risk of exposure for the workers and the public

Figure 6: Photograph showing laser ablation coating removal (LACR) on an interior plate girder of an in-service bridge

Figure 7. Photograph showing the plate girder after laser ablation coating removal LACR has removed the coating and a clean steel surface is ready to be recoated

Figure 6: Photograph showing the beam end after it has been recoated

7. Briefly describe the history of its development.

A team consisting of Virginia Department of Transportation (VDOT), Virginia Transportation Research Council (VTRC), FHWA, University of Virginia, and industry personnel conducted research on the LACR process in laboratory, shop, and in-service bridge locations to evaluate its effectiveness in removing coatings as while measuring environmental and industrial hygiene effects. In the near future, a report describing this work in detail will be made available to the public on the VTRC's website.

The research was divided into five phases:

- Phase 1 consisted of laser cleaning coated I-beam sections made of A36 steel (ASTM A36 Standard Specification for Carbon Structural Steel) removed from a decommissioned bridge structure in the VDOT Lynchburg District. Samples prepared using a traditional method, grit blasting, were also processed. Both the grit blasting and laser cleaning operations took place at the LACR representative's facility. The operation was documented and recorded and environmental hygiene data were collected.

- Phase 2 included an onsite field demonstration where LACR was tested on an in-service bridge structure in the VDOT Lynchburg District. An industrial hygiene assessment was conducted during this operation.
- In Phase 3, sections of a bridge bearing were transported to the LACR representative's facility, and another LACR test was performed. The purpose of this test was to determine whether the Adapt Cl1000 Watt laser was capable of cleaning the surfaces of recessed areas of the bridge beam, which were difficult to reach in the field-testing performed in Phase 2.
- Phase 4 explored LACR as a lead-based coating removal method. The purpose of Phase 4 was to determine the effectiveness of LACR in removing lead-based coatings from steel substrates, to provide a lead-free surface for further torch cutting of metal samples, a routine task performed by VDOT. Because traditional methods of hot metal cutting and shaping create high heat and usually lack vacuum systems, torch cutting and other traditional methods of hot metal cutting can cause large amounts of heavy metal fumes such as lead to be generated unless coatings are removed beforehand. This phase intended to determine if LACR could adequately prepare a surface so that torch cutting could be performed without PPE.
- Phase 5 was performed at Turner-Fairbank Highway Research Center (TFHRC) and included the evaluation of steel samples from Phase 1. During Phase 5, TFHRC coated the Phase 1 panels using coatings provided by VDOT. These coating materials were selected based on their ability to perform when applied on surfaces with minimal surface preparation.
- The research utilized an Adapt Laser Systems model CL1000QNd: YAG operating at a fundamental wavelength of 1064 nm and delivering 1 kW of average power.

The work led to the following conclusions.

- LACR effectively removes the coatings investigated, including lead-based alkyd paints. As was observed by previous researchers and by the present researchers for a previous investigation of a particular, epoxy-based coating; LACR can effectively remove coatings from steel substrates. The steel used in this research included legacy components, which had never been subjected to abrasive blasting prior to their original coating application. LACR was successful in removing coatings from steel with mill-scale (oxide from manufacture), though the substrate of the microscopic surface detail is distinct. Furthermore, although microscopic investigation reveals that small coating particles remain on the surface after cleaning (which are unapparent to the naked eye), these particles did not adversely affect subsequent coating adhesion.

- LACR does not detrimentally affect the mechanical properties or chemical composition of the steel (ASTM structural steel A36) that was examined in this study, despite the fact that microscopic investigation reveals very local (~ 1 micrometer thick) surface melting of the metal substrate (or the oxide which covers it). Measurements of the hardness revealed no degradation relative to the interior and the tensile yield strength, ultimate strength, ductility, fatigue strength, chemical composition were all on parity with expected values of A36 steel.

- The coating adhesion of LACR surfaces was determined to be satisfactory, with adhesion testing revealing average initial pull-off strength of approximately 1800 psi when an epoxy binder was used for recoating. The adhesion on a laser-cleaned surface was not consistently superior to the adhesion on a grit blasted surface. However, electrochemical test results indicate that the LACR surface was relatively nobler than the grit blasted surface. Coating color, gloss and rust creepage were similar when LACR cleaned surfaces and grit blasted surfaces were compared.

- Industrial Hygiene (IH) study results show that LACR provides a potential cost-benefit, since it does not require the type of containment or personal protective equipment (PPE) that traditional grit-blasting approaches require during coating removal (PPE is required when changing filters, which is an occasional operation). The engineering controls associated with LACR are effective in maintaining potential exposures for the laser operator below the current OSHA Permissible Exposure Limit (PEL) and OSHA Action Limit (AL). Of particular interest to this study was the detection of lead. The highest operator lead level observed was 4.3 microgram/cubic meter, which is below the AL (30 microgram/cubic meter) and PEL (50 microgram/cubic meter) for lead. This contrasts by nearly four orders of magnitude with the lead level observed during a comparable grit blasting operation. While the LACR's particle filtration system must be disposed of as hazardous waste, it should be noted that disposal of filters is a discrete and infrequent activity that can be performed under controlled conditions.

- LACR can be employed as a less hazardous method for localized removal of lead-based coatings in preparation for other processes, such as cutting, grinding or welding. These processes are routinely employed by bridge maintenance crews, and removal of lead-based coatings in advance of the processes reduces worker exposure. Lead levels in the personal air samples of operators who perform hot work (grinding and oxyacetylene torch-cutting) of steel with lead-based coatings are exposed to hazardous lead concentration many times in excess of regulatory limits, whereas hot work performed on steel cleaned in advance by LACR creates a lead concentration unlikely to cause exposure above regulatory limits. Results of bulk sample and lead wipe tests performed by VDOT did not show any measurable levels of lead, cadmium, hexavalent chromium, or PCBs on samples after cleaning with LACR. VDOT's evaluation of occupational hazards found that steel substrates prepared with LACR may be safely welded and cut with grinders or torches.

- LACR will not remove coatings sandwiched between two steel surfaces due to the inaccessibility of the coating. Note that LACR does not differ from traditional abrasive grit blasting in this regard, since neither technique is effective in removing coatings that are not accessible. Two welded "C channel" beams could not be cleaned effectively in the areas where the two channel surfaces made contact. This resulted in higher emissions during hot work that could cause exposure, but emissions were reduced greatly compared to cutting through a fully coated beam.
- Toxicity characteristic leaching procedure testing for Ag, As, Ba, Cd, Cr, Hg, Pb, and Se determined that some of the LACR's filters were considered regulatory hazardous waste. During Phase 1, the particle debris filter was determined to be a regulatory hazardous waste for lead. During Phase 2, the HEPA filter exceeded the regulatory waste requirements for lead and the particle debris filter for lead and chromium. Therefore, these filters must be disposed of or cleaned using the proper PPE for handling hazardous waste. However, it is noted that in both cases the LACR unit was not run to the point that the filtering systems were saturated and the system shut down or reached breakthrough. Accordingly, additional waste profiling of the HEPA and carbon filtering system components will be required as the LACR operation is scaled up.

Click or tap here to enter text.

State of Development (40 points)

Innovations must be successfully deployed in at least one State DOT. The AII selection process will favor innovations that have advanced beyond the research stage, at least to the pilot deployment stage, and preferably into routine use.

8. How ready is this innovation for implementation in an operational environment? Please check of the following options. Please describe.

☐ Prototype is fully functional and yet to be piloted

☒ Prototype demonstrated successfully in a pilot environment by VDOT

☒ Technology has been deployed multiple times in an operational environment - by the Department of Defense

☒ Technology is ready for full-scale adoption

The AASHTO Committee on Bridges and Structures Annual State Bridge Engineers Survey for 2017 included the following: Has your agency evaluated High Wattage Lasers for Coating Removal?

2 (4.4%) YES

43 (95.6%) NO

Check your agency's highest level of use for High Wattage Lasers for Coating Removal.

2 (100.0%) Laboratory environment with project specimens

From the results of this survey, Virginia is one only of two state DOT's that has evaluated lasers.

Virginia's evaluation has gone beyond a laboratory environment with project specimens to include use at an in-service bridge.

Manufacturers of Laser coating removal equipment include the following companies:

- Adapt-laser - https://www.adapt-laser.com/
- Sur Clean - https://www.surclean.com/
- Powerlase - https://www.powerlase-photonics.com/
- P-Laser - https://www.p-laser.com/

Service providers for Laser coating removal included the following companies:

- Maviro - https://www.maviro.com/services/laser-services
- TLC Metal Restoration - https://www.tlcmetalworks.com/metal-finishing-services/laser-paint-stripping-laser-surface-cleaning/
- Norton Sandblasting - http://www.nortonsandblasting.com/nsblaserclean.html
- Alliance Painting and Laser Ablation - https://alliancepainting.ca/hazardous-coatings-removal/laser-ablation-technology/

9. What additional development is necessary to enable routine deployment of the innovation? What resources—such as technical specifications, training materials, and user guides—are already available to assist with the deployment effort?

Laser ablation coating removal (LACR) has been successfully deployed in the laboratory, shop, and the field at an in-service bridge. In the near future, a report describing this work in detail will be made available to the public on the VTRC's website.

The field studies to perform coating removal on the in-service bridge beam-ends and bulkheads with the Adapt Laser System were effective in open spaces but were more problematic in tight spaces where geometry limited access to the coated surface.

We recommend that Adapt Laser equipment be modified with an Optic Mirror Module for Beam Deflection and that LACR equipment from two other manufacturers (SurClean and Power Lase) be investigated to determine if the tight space issues can be resolved.

A generic specification is available for the laser equipment.

Additional deployment measures will involve the preparation of a contract for the purchase or rental of the equipment, training for operators and disposal of the filters.

10. Has any other organization used this innovation? ☒ Yes ☐ No

If so, please list organization names and contacts. Please identify the source of this information.

Organization	Name	Phone	Email
Centre of Innovation (Marine & Offshore Technology), Ngee Ann Polytechnic, Singapore 599489 http://www.jlps.gr.jp/jlmn/upload/036fdaaa5f84e8dbe2e21bb1ccf3631e.pdf	G. X. Chen , T. J. Kwee , K. P. Tan , Y. S. Choo, and M. H. Hong	Click or tap here to enter text.	elehmh@nus.edu.sg
The Department of Defense is leading the way in application and use of laser coating removal technology. - https://www.industrial-lasers.com/surface-treatment/article/16485585/applications-of-laser-coating-removal-technology	James J. Arthur	Click or tap here to enter text.	arthurj@ctc.com
Strategic Environmental Research and Development Program (SERDP) Environmental Security Technology Certification Program (ESTCP)	Gerard Mongelli	937-306-3310	mongellg@ctc.com

https://www.serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Surface-Engineering-and-Structural-Materials/Coating-Removal/WP-200027/WP-200027			
US Air Force's (USAF) Travis Air Force Base (AFB) in California - https://www.airforce-technology.com/news/usafs-travis-afb-tests-laser-technique-remove-corrosion/ https://www.dvidshub.net/news/269094/travis-beta-tests-lasers https://www.349amw.afrc.af.mil/News/Article-Display/Article/1162030/technology-of-the-future/	Brian Brown		

Potential Payoff (30 points)

Payoff is defined as the combination of broad applicability and significant benefit or advantage over other current practice (baseline).

11. How does the innovation meet customer or stakeholder needs in your State DOT or other organizations that have used it?

Current practice requires the construction of containment structures for removal of existing coatings on highway bridges. Although coating failures are generally limited to 15% of the total beam/girder length, the economics of containment structures often lead to the decision to recoat entire structures rather than only the beam/girder ends.

Deployment of Laser Ablation Coating Removal (LACR) would allow for the removal of coatings only at the ends of beams/girders and to do so without containment, therefore, VDOT could potentially address more of its coating needs with current budgets.

Use of LACR has the potential to significantly reduce worker exposure to hazardous conditions, as laser-cleaned surfaces have been shown to be safe for hot work such as grinding, torching and cutting. LACR would reduce the number of lane closures required to perform recoating, as beam ends are often accessible without closing lanes.

12. What type and scale of benefits have your DOT realized from using this innovation? Include cost savings, safety improvements, transportation efficiency or effectiveness, environmental benefits, or any other advantages over other existing baseline practice. Please identify the following benefit types:

Check boxes that apply	Benefit Types	Select a rating from the drop-down menu
☒	Cost Savings	7-Exceptional
☒	Shortened Project/Service Delivery Schedule	5-High
☐	Improved Customer Service	Choose an item.
☐	Improved Quality	Choose an item.
☒	Environmental Benefits	5-High
☐	Organizational Efficiency	Choose an item.
☒	Improved Safety	6-High to Exceptional
☒	Improved Operation Performance	4-Moderate to High
☒	Improved Asset Performance	6-High to Exceptional
☐	Other (please describe)	Choose an item.

Provide an additional description, if necessary:

The applications envisioned for laser ablation coating removal are (1) cleaning of beam/girder ends or limited zones of structural steel threatened by corrosion, prior to repainting, and (2) removal of paint from small portions of beams or other steel members, prior to hot work such a grinding, welding or torch cutting. The use of LACR for beam end coating offers the possibility of significant improvement in systemwide bridge durability, since many more bridges could receive recoating with a particular recoating budget. LACR offers a means of avoiding operator exposure to heavy metals during hot work at a small environmental containment cost.

13. Please describe the potential extent of implementation in terms of geography, organization type (including other branches of government and private industry) and size, or other relevant factors. How broadly might the technology be deployed?

Laser ablation coating removal (LACR) would be deployed by VDOT across the entire state of Virginia.

A summary of the research has been presented to TRB and AASHTO groups, and there is interest from other state DOTs, therefore, there is potential for deployment at the national level.

Market Readiness (20 points)

The AII selection process will favor innovations that can be adopted with a reasonable amount of effort and cost, commensurate with the payoff potential.

14. What specific actions would another organization need to take along each of the following dimensions to adopt this innovation?

Check boxes that apply	Dimensions	Please describe:
☒	Gaining executive leadership support	This is an innovative technology and gaining support of executive leadership is important. Demonstration of its practical value will enhance interest.
☐	Measuring performance (e.g. benefits documentation)	Click or tap here to enter text.
☒	Improving technology understanding	There is a need for some training to explain the uses of the LACR
☒	Overcoming financial constraints	Funding to rent or purchase the equipment will need to be obtained from the agency.
☐	Addressing legal issues (if applicable) (e.g., liability and intellectual property)	Click or tap here to enter text.
☒	Acquiring in-house expertise	If work is contracted out, no additional expertise is needed. If work is done with in-house forces, some (minimal) training is required.
☐	Resolving conflicts with existing regulations and standards	Click or tap here to enter text.
☐	Other Challenges	Click or tap here to enter text.

15. What is the estimated cost, effort, and length of time required to deploy the innovation in another organization?

Please describe:

Cost: Approximately $604,000 to purchase equipment, including Laser Fume Extractor Filter Unit, Formal Safety & Use Training for Qualified Laser Operators and Laser System Scheduled Preventive Maintenance.

Approximately $13,200 per week to rent equipment, plus a one-time cost of $4,537 for Formal Training for Authorized Laser Operators with On-Site Technical Support.

Level of Effort: Virginia has completed the basic research, and after we complete preparation of contract documents for the purchase or rental of LACR equipment, the level of effort for another state to adopt the technology should be moderate.

Time: Virginia is willing and excited to share our research and contracting procedures, and we intend to publish our guidance, specifications and implementation process for anyone to access. Therefore, the time required for another state to implement the technology should be less than 24 months. VDOT has presented the findings of its program and research at several national and regional conferences, and the response has been significant interest. We have had inquiries from other DOTs who have sought the details of how the technology would be employed.

16. To what extent should the implementation of this innovation require the involvement of third parties, including vendors, contractors, and consultants? If so, please describe. List the type of expertise required for implementation.

In addition to VDOT/VTRC staff, implementation will involve vendors and contractors.

The vendors/contractors will be required to demonstrate prior successful application of laser technology to remove coatings from bridge structural steel.