NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Natural Gas Engine Development Gaps

Natural Gas Vehicle Technology Forum – Brookhaven National Laboratory
Upton, New York

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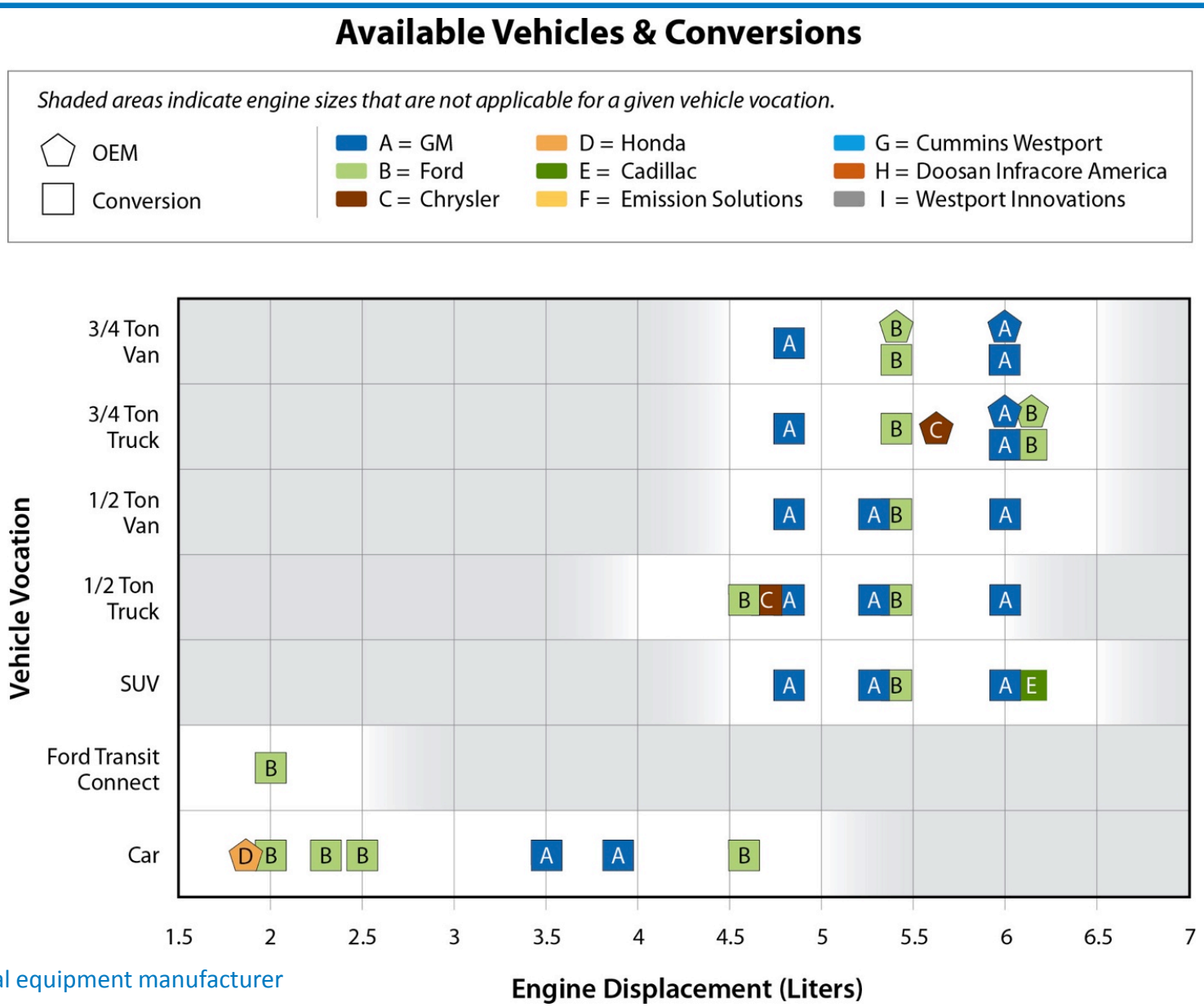
Outline

- Review of current natural gas vehicle (NGV) offerings
- How to identify and address NGV development gaps
- Major NG engine development gap areas

Light-Duty NGV Offerings

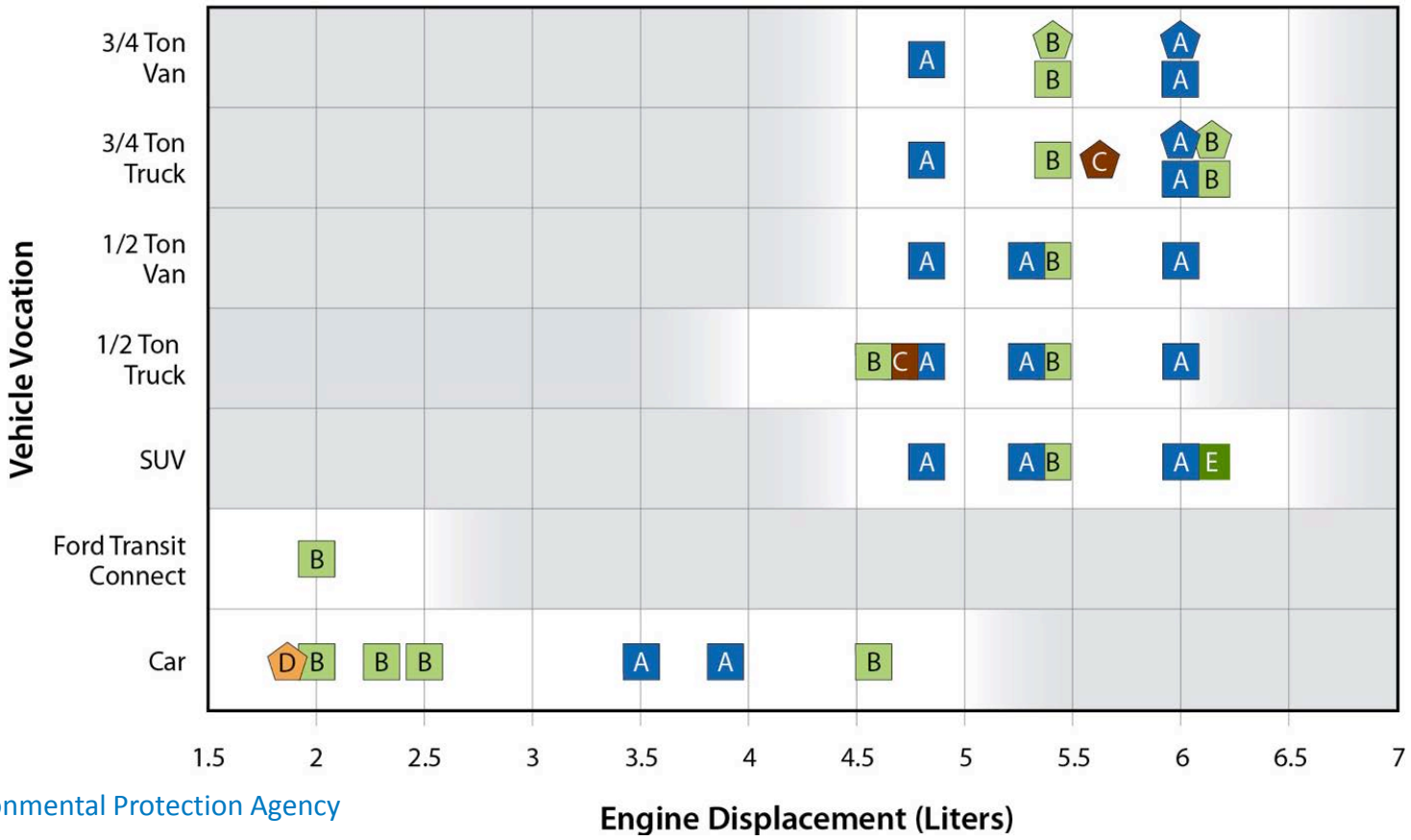


OEM = original equipment manufacturer

Light-Duty NGV Offerings

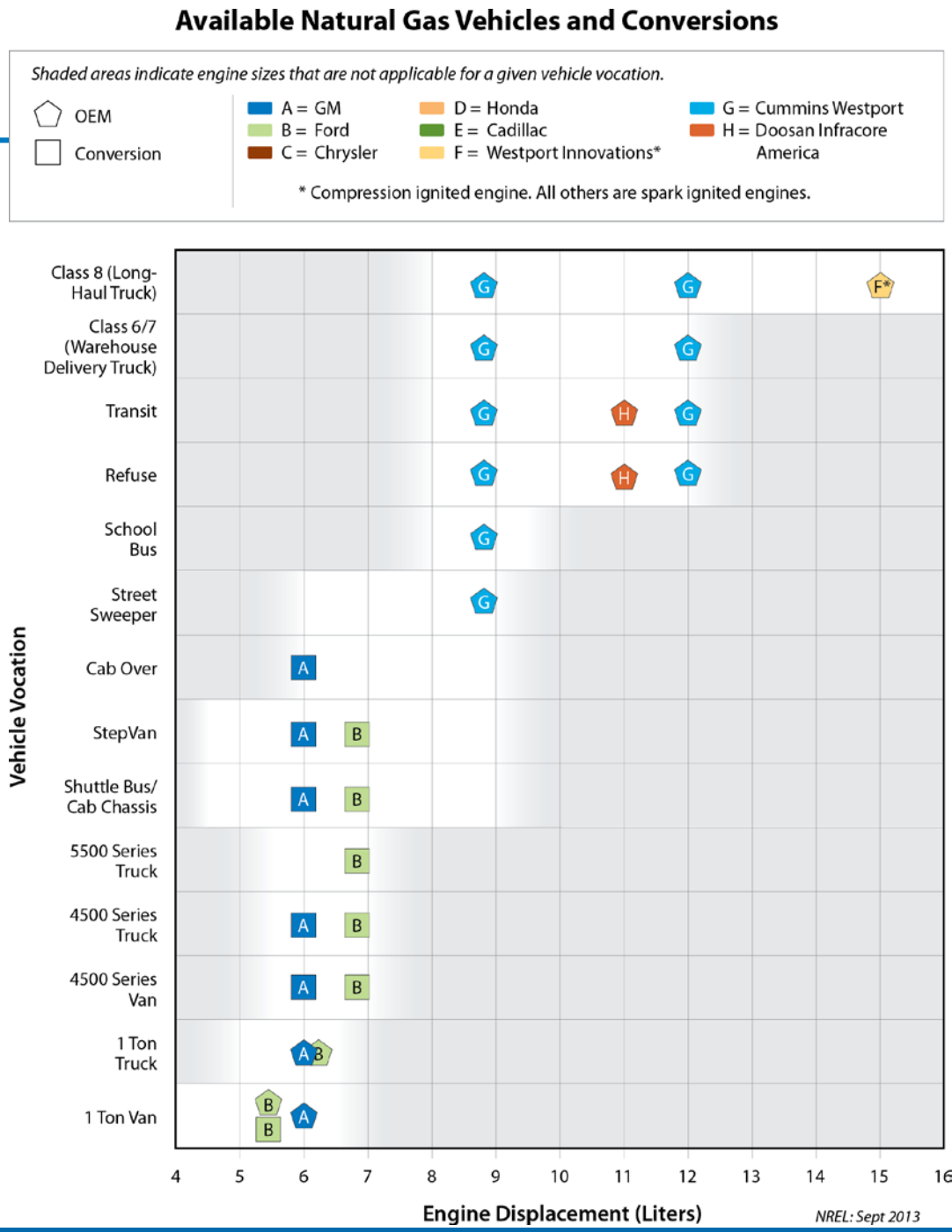
General observations:

- Offerings are increasing in response to market
- EPA rules offer more flexibility for conversions
- OEMs have themselves reentered market along with 3rd party support
- Light-duty market is building range and diversity



EPA = U.S. Environmental Protection Agency

MD & HD NGVs



HD = heavy duty
MD = medium duty

MD & HD NGVs

- The “lighter” end of the market is covered with OEM options and conversions based on gasoline engines

MD & HD NGVs

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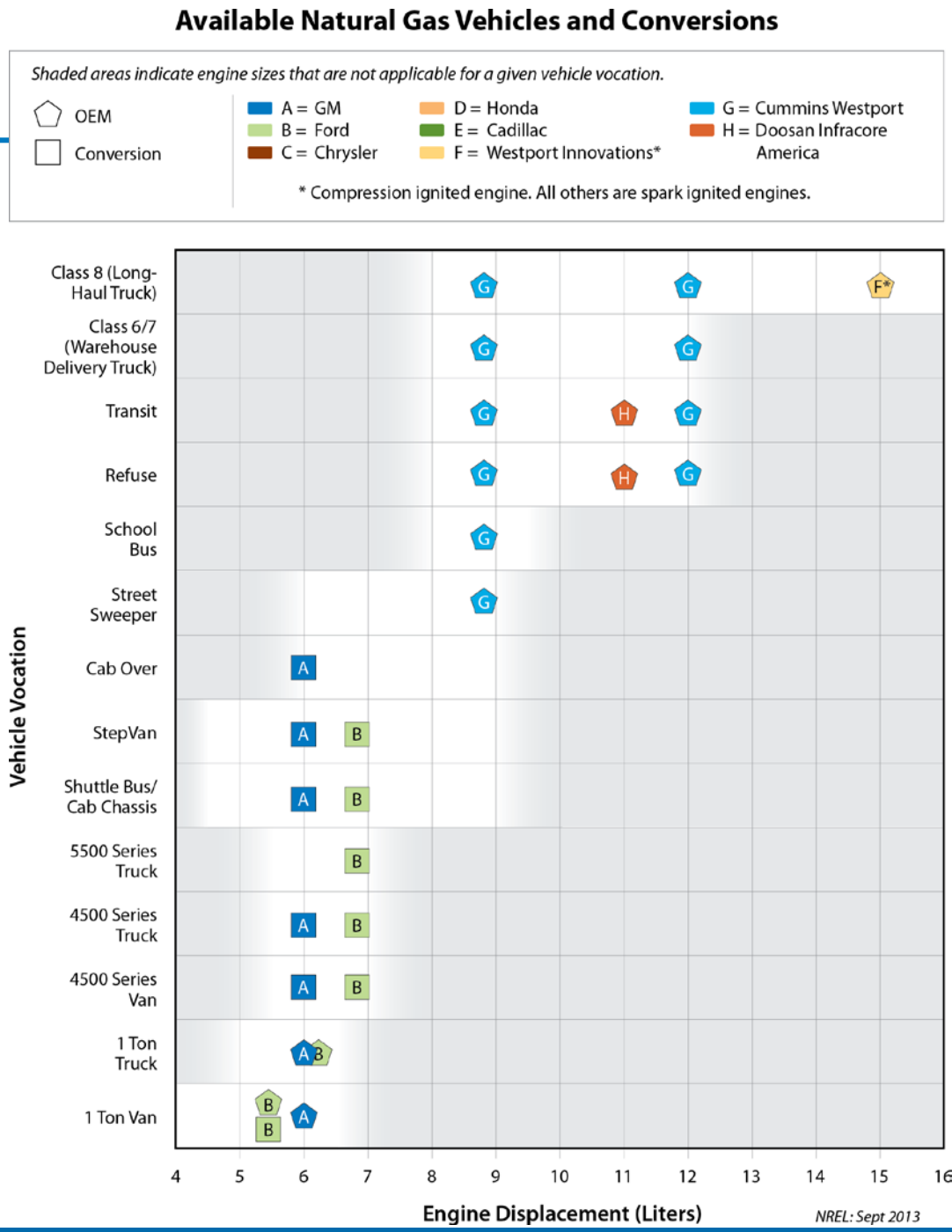
- Initial development of the Cummins Westport 6.7L ISB6.7 G is now underway.

MD & HD NGVs

- The “heavy” end of the market is generally based on spark-ignition compressed natural gas (CNG) / liquefied natural gas (LNG) or compression–ignition dual fuel CNG / LNG + diesel conversions of diesel engines.



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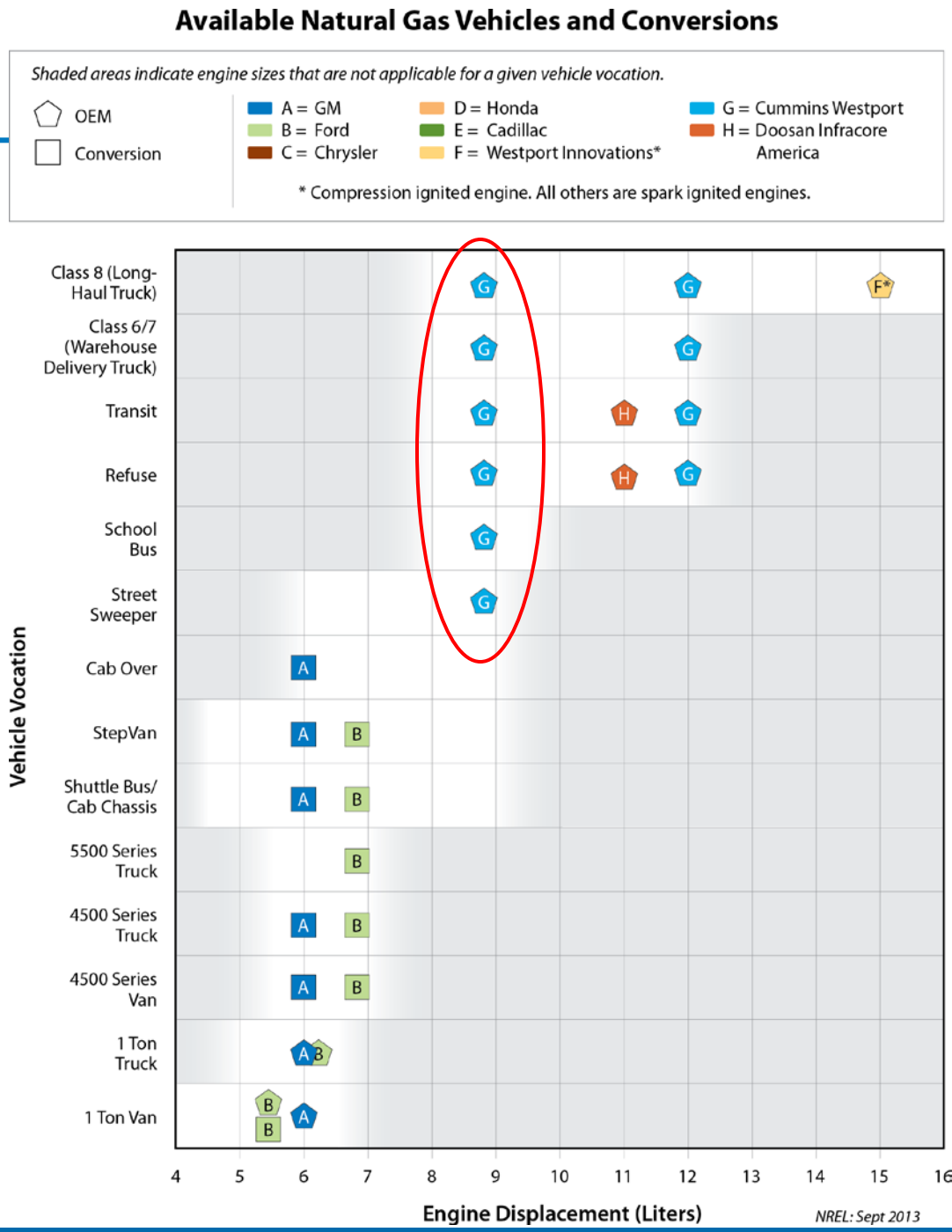

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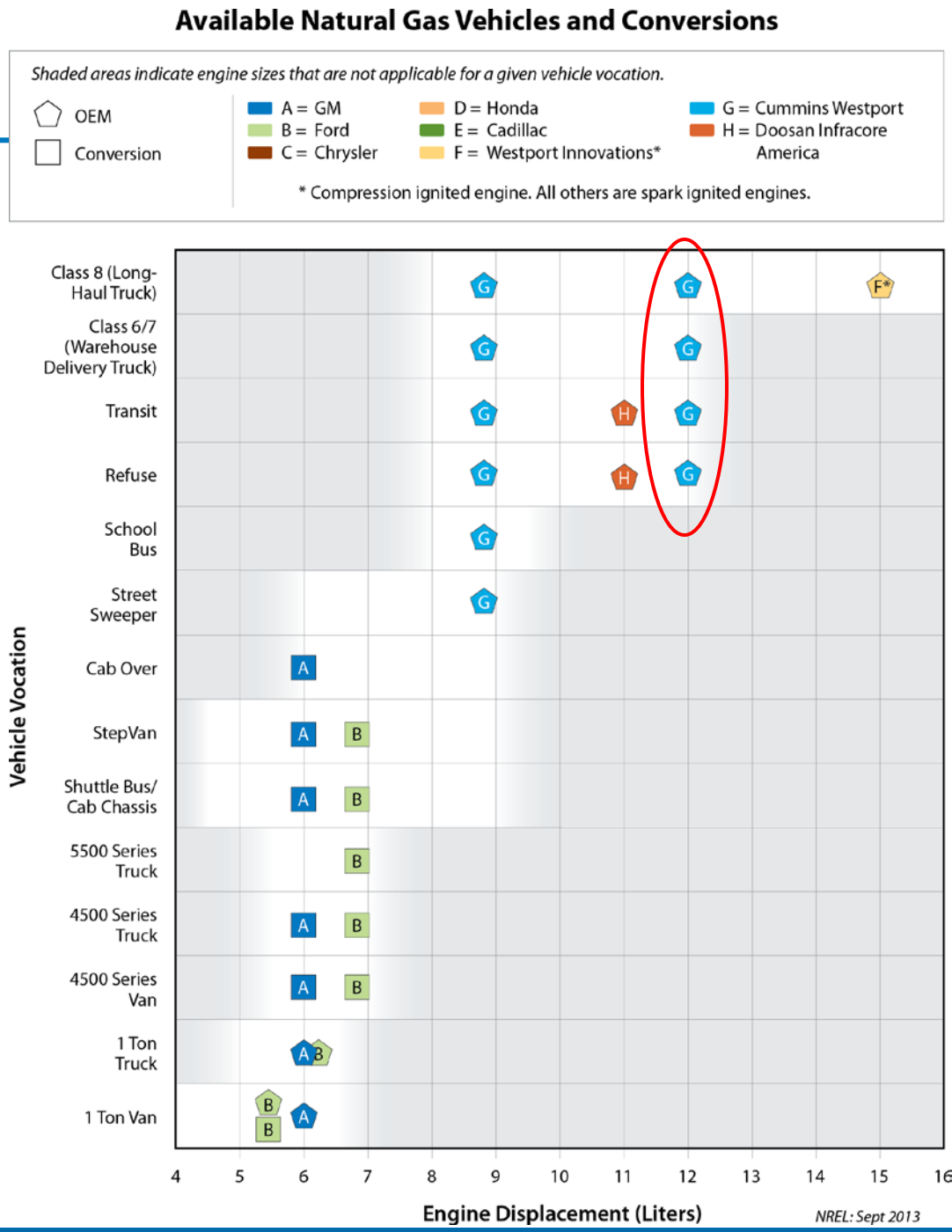

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- And Southwest Research Institute is working with Doosan on a significantly upgraded version of the 11L.

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HPDI = High Pressure Direct Injection

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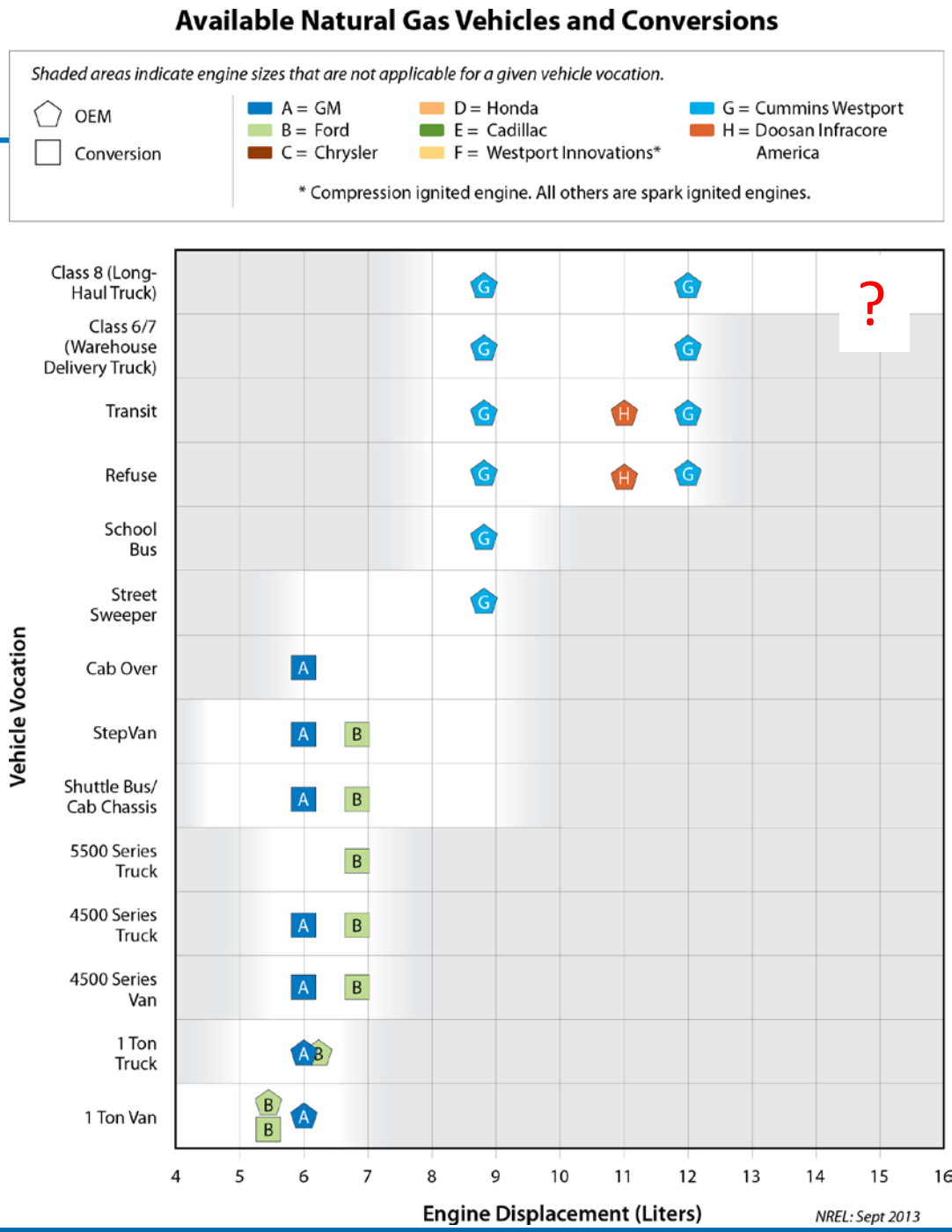

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- Volvo announced that a new dual fuel (HPDI) D13-LNG engine will be available mid-2014.

Stakeholder Input is Critical

NGVTF uses a roadmap developed by the CEC as a foundation for its work. Based on NGV research, development, demonstration, and deployment gap analysis, and stakeholder views, this roadmap suggests the following would accelerate commercialization of NGV technologies in the market:

- Engine development and vehicle integration
- Fueling infrastructure and storage
- Technical and strategic studies

Source: http://www1.eere.energy.gov/cleancities/natural_gas_forum.html

Stakeholder Input is Critical

- Past input directed co-funding for NG engine and vehicle research and development
  - CEC – Initial development of Cummins Westport 11.9L (GTI)
  - NREL (DOE/CEC/SCAQMD) – Final development of Cummins Westport 11.9L
  - NREL (DOE/CEC/SCAQMD) – Development of Doosan 11L (SwRI)
  - CEC – Initial development of Cummins Westport 6.7L (GTI)
  - Other NG engine development
  - Development of storage technologies
- What are current / future needs?
- NREL is assisting CEC in updating its NGV research roadmap

SCAQMD = South Coast Air Quality Management District
GTI = Gas Technology Institute
SwRI = Southwest Research Institute

NG ~~Engine~~ *Vehicle* Development Gap Areas

- Some of the gaps are not limited to engines alone
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  - Additional on-board storage improvements are necessary:
    - Higher capacity
    - Smaller package
    - Lighter package
    - Lower cost
  - R&D underway
    - CEC – adsorptive technologies
    - DOE's Advanced Research Projects Agency - Energy (ARPA-E): advanced storage, lower cost home compression, etc.…

NG Engine Development Gap Areas

- **Increased engine efficiency**
  - Current trend in HD NG engines is spark-ignited, stoichiometric, cooled exhaust gas recirculation (EGR), with a three-way catalyst
  - Need to reduce fuel efficiency penalty compared to diesel
  - Low NG fuel costs may not last forever, so research is necessary now to reduce the fuel efficiency gap
    - Reduce operating costs
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- **Potential pathways**
  - Improved fuel injection systems (port, direct)
  - High dilution (EGR)
  - High boost
  - Improved ignition systems
  - Reforming for syngas / H_2 to extend ignition limits
  - Low-temperature combustion strategies (like homogeneous charge compression ignition [HCCI])

NG Engine Development Gap Areas

- **Reduced emissions**
  - Regulated emissions
    - GHG / CO_2 equivalence (concerns over tailpipe methane)
    - Driving some regulated emissions lower
    - CARB and SCAQMD R&D funding programs develop technology for sub-0.02 g/bhp-hr vs. 0.2 g NO_x standard
  - Unregulated emissions
    - Ammonia (desire for sub-10 ppm)
  - Will programs like California's Carl Moyer Program incentivize sales of these engines?
  - California is an important market and will influence future NG engine technologies. Meeting current standards isn't enough.

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- **Potential pathways**
  - Same list as fuel efficiency enablers
  - Cold-start / low-temperature catalyst operation focus
  - Additional aftertreatment (selective catalyst reduction?)

NG Engine Development Gap Areas

- **Engine development / certification process**
  - EPA / CARB HD emissions certification is challenging
    - 22,000 hour / 435,000 mile “full useful life” requirement
  - Unlike light-duty gasoline engines, which have bench-aging protocols for deterioration factor (DF) testing for emissions
  - HD tests engine + aftertreatment system together in an accelerated manner (ideally very accelerated)
  - This is a significant (cost, timing, resources) hurdle for engine OEMs (too big for some)
  - Sales limited to 300 engines / year without this DF testing
  - This issue will become more challenging with increasing emissions standards (0.02 g/bhp-hr NO_x)
  - Coordinated development of catalyst aging protocols could satisfy EPA / CARB needs and reduce the certification DF “hurdle” for OEMs

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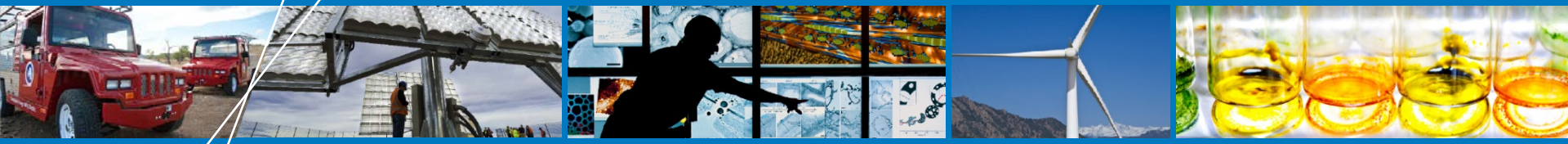
Thank you for your interest and feedback.



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