Sustainable Transport

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Technological advances enable and influence the development of larger, denser urban areas, offering greater access to stronger, more diversified urban economies with better services and opportunities leading to an improved overall quality of life. For the first time in human history, in 2008 more than half the world's population lived in cities. By 2030, 5 billion people are expected to live in high density urban areas. This migration can have positive consequences to the environment, in that large cities are more energy efficient and resulting in a lower per capita carbon foot print (as an example, a New York City resident's carbon foot print is 30% that of a suburban or rural counter part). However, this also comes with a serious set of challenges that must be mitigated in a sound manner for such benefits to materialize:

- Careful urban planning from the perspective of optimizing high-demand land and space (housing, work space, parks and green surfaces, parking, walking and biking paths...)
- Transportation systems that are effective and sustainable: Integrated, efficient and affordable transport systems for people and goods that will reduce/eliminate the need for personal cars
- Pollution mitigation: Means and systems to mitigate/ eliminate greenhouse gases, NOx (nitrogen oxide) emissions, particulates, and heat island effects from buildings and vehicles
- Natural resource management: Systems and technologies that enable the reuse of refuse material and minimize water and energy consumption (sewer systems, water and energy)

The International Energy Agency (IEA) predicts that transport energy use and emissions will increase by more than 50% by 2030 and more than double by 2050. In the US cars and light trucks emitted nearly 1.2 billion metric tons of carbon dioxide (CO_2) emissions, or 17% of the country's total in 2009. In the UK, nearly 21% of the country's CO_2 is generated by domestic transport dominated by passenger cars.

Considering both the challenge and the opportunity presented by the transport sector in terms of enabling efficient and sustainable modern cities and supporting a greener and healthier planet, governments with a pull from their citizens and green focused organizations are funding initiatives in support of implementing and proliferating sustainable transport systems. A key enabling technology, identified by the Intergovernmental Panel on Climate Change (IPCC) is hybrid propulsion which, when implemented in transit buses and vocational medium and heavy duty trucks results in fuel consumption, CO_2 and greenhouse gas emissions reduction by 20% to 40% depending on duty cycle, vehicle type and hybrid power train architecture, when compared to their corresponding conventional counterparts.

Achieving and delivering a heavy duty hybrid solution that addresses the demand for sustainability is a rather complex task and can be approached in several ways. The complexity stems from the need for the corporations investing in such endeavours, beyond their corporate and social responsibilities, to realize a return on investment while providing a product that meets the expectations of the end users, including affordability. After all, the ability of these corporations to continue developing and producing such technologies and others that serve their nations and communities, is primarily founded on their profitability and ability to reinvest a portion of their profits in technology development and maturation. This means that the product must provide the best performance in terms of fuel efficiency, reliability, reduced emissions, lower operating costs, passenger comfort, and lower noise, while keeping the cost of its production as low as possible.

Different companies with different cultures and pedigree have varying views on the best way to achieve a balanced (cost vs. performance) equation. In BAE Systems' view, meeting the challenges of our modern society and fulfilling our responsibilities towards our children and communities for a better tomorrow, requires a paradigm shift in the way we develop and produce enabling products and technologies. BAE Systems relies on 60 years of experience in power management and control for commercial and military aircraft and leverages systems integration approaches to develop hybrid propulsion solutions. To achieve a sustainable offering in hybrid propulsion requires a complete understanding of its mission, the way it is used, the way it is supported in the field, the value proposition that would be acceptable to the market place and how it will evolve in the next 20 to 50 years. Other important considerations include an understanding of the geopolitical environment that shapes the various global markets, local policies vis-à-vis the environment, energy, and the acquisition process of such vehicles and fleets. Furthermore, another key element in driving technology acceptance and accelerating product maturation is the careful consideration of potential adjacent markets and applications for components, subsystems and perhaps the entire system altogether (military, light rail and renewable energy are examples of adjacent markets that are under consideration by BAE Systems, depicted in figure 1). The intimate understanding of this multifaceted ▶

puzzle, allows for a sound business model to be put in place that is synergistic with the specifics and the "culture" of the target market of interest. This includes partnership strategies that bring together the right team members, supply chain, vehicle OEMs, end-users, policy makers, local communities and others. This philosophy supported investment in developing, maturing and delivering a viable portfolio of hybrid propulsion and power management solutions branded as HybriDrive® by BAE Systems for transit/city buses and commercial truck platforms.

One of the major barriers to a widespread new propulsion technology acceptance such as hybrids, in addition to the need for a cultural change, is its cost premium when compared to conventional heavy duty vehicle propulsion products. A number of actions must be put in place to mitigate such hurdles:

1. Educating the OEM and the end-users: Every effort is made during the design and development of such technologies to make their implementation and use as transparent as possible to the OEMs and end-users. The idea is to minimize/eliminate the need for specialized skills and additional training, as well as the need for cost prohibitive vehicle redesign to accept these new power trains. However, the fact remains that electric components operating at high voltage and power levels are unknown and therefore intimidating to the general public. A great effort is applied toward explaining and demonstrating the simplicity, the safety and the benefits of these technologies. Further, implementing a thought process that focuses on life cycle costs is critical to overcoming the initial negative perception of the acquisition price of such technologies.

2. Governance and policy shaping: Although hybrid propulsion technology is becoming more accepted, the fact remains that the local and national policies that govern mass transit and commercial vehicles certification, acquisition and operation are written around the combustion engine technology. Examples include emissions certification, On Board Diagnostics (OBD), vehicle safety requirements and so on. The growing commitment of governments to prioritize sustainable transport systems, clean air, economic growth (job creation), and the need to mitigate rising energy prices and dependence on foreign oil (national security), have helped hybrid technology suppliers and supporters to make progress in influencing upcoming regulations. Stressing the importance and the need to allocate portions of tax payers' money in support of the development, maturation and proliferation of these technologies is paramount. Such critical efforts must continue into the future. Corporations such as BAE Systems have embraced this approach and have been working with the US Government (Congress), the Department of Energy, the Federal Transit Administration, the National Renewable Energy Laboratory, CALSTART, WESTART, CARB, HTUF, NVC and local Transit Authorities and others to accelerate the commercialization of hybrid technologies.

3. Stimulating Economies of scale: One key element of the strategy to accelerate the widespread use of the technology is to work in concert with fleet users, OEMs and the supply chain to minimize and eliminate the cost barrier that's holding back initial hybrid volumes. The dilemma is that for cost to come down, volumes must go up, however, for volumes to go up, the cost must come down.

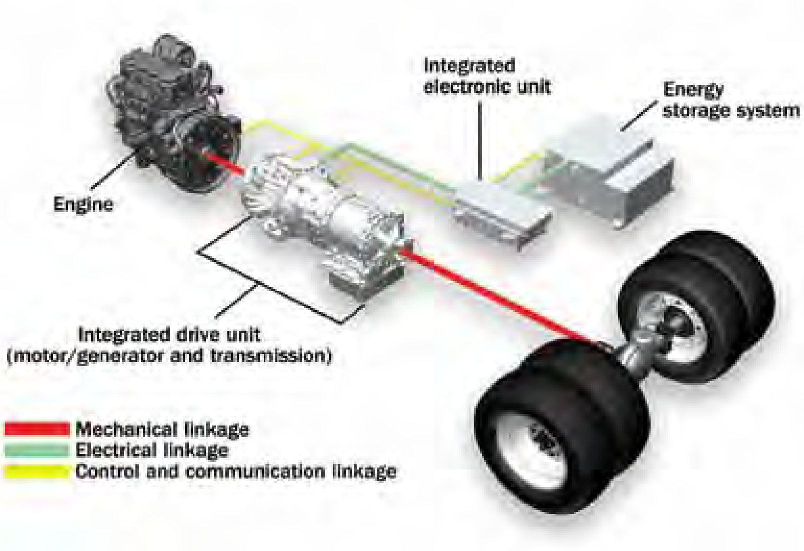
Initiatives to break this vicious circle, to include out-of-the-box, paradigm shifting design and development approaches that minimize cost and provide flexible and scalable components are critical. Such components will provide enticing solutions in other applications beyond the hybrid propulsion market. Further, a dual use design philosophy that is inclusive of potential military applications offers the opportunity for further technology deployment and maturation in support of increased volumes and lower cost.

Several steps must be put in place;

a. Design and development programs must assume a commercially viable standalone end product. This means that all efforts must be made to provide an affordable product without subsidy. While this constraint might not be met in the end, the goal is to seek the creative approaches that would result in the lowest cost system, ensuring the business case is solvable on the supplier side, as well as on the end-user side by providing a pay-back on the initial price premium well within the life of the vehicle.

b. The system and its components must be designed with the greatest possible flexibility and scalability within the limits of a solvable business case. The purpose here is to obtain a set of components that can be scaled up and down their power and torque capabilities without prohibitive redesign. This way, additional applications and adjacent markets can be accessed. The purpose is to enable economies of scale via increased volumes, increased affordability, accelerated maturity, therefore enabling faster proliferation of the product. This approach allows access to a larger number of vehicles within the same market: example 12m buses, articulated 18m buses, fuel cell buses, CNG buses and trolley buses. It also allows for access to vehicles of a different type, such as light rail where the propulsion power and torque levels are very similar to those of heavy duty transit buses and trucks. Further, the scalability allows for the components to be used within completely different applications where high efficiency, reliability, advanced control and smart power management are critical discriminators. Examples of such applications include wind turbine, solar power and maritime applications.

c. Inclusion of the military market to the greatest extent possible is another key element of the strategy. While th▶



mission profile of a combat or tactical military vehicle differs from that of a commercial truck or bus, the actual components of a commercial hybrid propulsion system can be implemented in such a way that supports the specifics of the military vehicle and market. The stringent constraints on government budgets combined with the changing conflict types is creating the need for the DOD and MOD to reduce the logistical foot print of the armed forces in the battlefield. Fuel remains the largest tonnage of material transported into and within the battle field at a delivered cost in the hundreds of dollars per gallon in the most remote missions. Hence, improving fuel economy equates to reducing battlefield cost (tax payer's money), and reducing the number of deployed personnel. However, while these departments represent a significant number of vehicles (hundreds of thousands), they could neither entice sufficient competition and volume to support a sustainable market nor the investments needed for a broad industry capability. This situation has led the military leaders to start adopting commercial practices when it comes to developing and deploying new capabilities and products. Starting with advanced commercial systems reduces non-recurring engineering budgets, accelerates final capability deployment and reduces acquisition costs.

Military vehicle specifics include:

i. Mobility improvement: Whereby implementing onboard power generation and management solutions by leveraging the power converters and the electric machines of the commercial hybrid systems, capabilities such as vehicle cabin air-conditioning, engine cooling, accessory electrification and mission equipment power needs are met with improved efficiency. This in turn results in releasing additional power back to the wheels or tracks for improved mobility (acceleration and grade climbing). Further, fuel consumption is also reduced resulting in increased vehicle range and reduced logistic support needs.

ii. Vehicle battle field capability improvement: Enhanced onboard power generation and management also provide the opportunity to equip military platforms with much needed enhanced mission equipment which would not be supported with conventional power trains, thereby enhancing vehicle's effectiveness in completing its mission.

iii.Export power capability: Much of the electric power that is generated in remote military bases is done via towed electric generators that are fuel hungry, heavy and bulky. The implementation of an advanced on board power system combining generation and management allows for the actual vehicles, when stationary, to generate electric power and support the needs of the bases, hence eliminating the need for towed generators during initial deployments, expeditionary forces and/or in times of acute need.

iv. Stationary generators themselves can be made more efficient by operating at variable load-dependent speeds using synthesized output power rather than the traditional fixed speed synchronous power.

4.Securing incentives: Analyses carried out by Groups such as HTUF (Hybrid Truck Users Forum) show that production and acquisition of hybrid vehicle volumes in the 3000 to 5000 units per year will enable sufficient price reductions to justify purchase based on the business case alone (no subsidies required). However, in order to achieve such volumes initially, additional incentives must be put in place. HTUF and its working groups, including end-users, OEMs and suppliers, were able to secure and push into actual practice, federal tax credits under the Energy Policy Act of 2005 (EPAct 2005). This incentive was the first statutory acknowledgement of the uniqueness of medium and heavy duty hybrids. The working groups are working on a multi-level strategy to help secure better incentives at the federal level, while also working with States and regions to encourage and secure matching or supporting incentives at that level. Such incentives are designed to be time limited (3 to 5 years), enough to increase the volumes to the tipping point level and reduce acquisition price to the point where the premium is paid by the benefits of reduced vehicle life cycle costs (fuel savings and reduced maintenance). Such incentives have been put into practice for the mass transit market several years ago whereby the federal government subsidises the acquisition of hybrid and other clean alternative technologies. Today, close to 2000 hybrid buses are acquired in the USA every year. Efforts to reduce cost and increase fuel economy supported by the increasing fuel prices are stimulating yearly production increase towards a sustainable market. Similar activities are taking place in the UK where carbon credits and other types of incentives are being defined and pushed into practice.

The BAE Systems HybriDrive® family of products development started 20 years ago. Focus on adjacent markets and interest in environmentally friendly technologies led to investing to develop hybrid propulsion solutions for wheeled heavy duty vehicles. The first member of the HybriDrive® portfolio was the BAE Systems' Series propulsion system. This best in class ▶

technology, is leading the global hybrid transit bus market with over 3,200 systems in revenue service across North America and the UK, surpassing 300 million revenue service miles and saving 25 million gallons of fuel cumulatively while preventing 280,000 tons of CO2 from being released into our atmosphere. Beyond its demonstrated superior fuel economy, emissions reduction, flexibility and scalability to support various transit bus platforms, it offers a viable path to a Zero Emissions Vehicle. Further, the prime mover and the associated electric power generator can be replaced with other power sources, such as Fuel Cells, Plug-in batteries or overhead power grid, leading to pure electric mass transit vehicles. The largest fleet of hybrid transit buses in the world is in New York City with a total of 1,675 buses, all contributing to the sustainable urban economy and the well being of the local communities. Statistics show that the local economy benefits from the overall savings due to a smaller personal car population, shorter travel distances and heavier mass transit use, resulting in cumulative savings of $19 billion per year of which approximately $16 billion are spent within the city.

Over the last two years, an additional product has been under development and will be added to the BAE Systems HybriDrive® portfolio by the end of 2012 (production ramp up). This is the Parallel hybrid propulsion system, targeting primarily the heavy duty vocational truck market. After a thorough analysis of the global vocational truck market in terms of fuel consumption, noise pollution, greenhouse gas and CO2 emissions, the determination was that considerable improvements can be made to achieve further environmental friendliness and leap towards transportation sustainability by providing the right hybrid propulsion power train. The Parallel system is different from the Series system in that both combustion engine power and electric power are blended to provide vehicle propulsion and enhance vehicle performance (combustion engine and electric machine are both connected to the vehicle wheels via a propulsion shaft, unlike the Series system where the wheels are connected to the electric traction motor only). The anticipation is that within the vocations of interest (refuse collection, pick and delivery, construction…etc), fuel savings and associated emissions reductions will be in the 20 to 30%.

While progress is being made in the development, maturation and commercialization of hybrid drivelines, much more must be done in order to realize the full potential of this technology and enable a commercially viable path to the Electric Vehicle end-state. The progression towards this end state will be made via the coexistence of various technologies and options as they gain commercial viability over the next 10 to 20 years. Meanwhile, several areas require continued attention and work:

- Legislative and governance: Emphasis on the need for incentives and allocation of funding in support of green sustainable transport systems must continue well into the next decade. Further, regulations and standards that support the proliferation of hybrid technology have yet to be developed.

- Electric accessories: Components such as electrically driven air-conditioning, cooling fans, steering pumps, air-compressors and such do not currently exist and/or are not in an optimized format for heavy duty vehicles. Much work is yet to be done to develop the products and establish a supply chain that can produce them for the right cost. These components are critical to achieving additional fuel consumption and emissions reductions, and to supporting the progression toward a future pure electric vehicle.

- Energy storage: The current performance and the future viability of hybrid propulsion systems rely to a greater extent on the performance of the energy storage. However, current battery and ultra-capacitor technology is too costly, does not have the life expectancy, nor the energy and power density required to enable long range EV operation (engine off) for a commercial vehicle, and currently does not offer a viable path to a pure electric vehicle end-state. Further development of energy storage technology must remain an area of great focus well into the next 2 decades.

- Fuel cells: Fuel cell technologies remain a promising approach to support zero emission vehicles of the future. Progress has been made in improving the robustness, reliability, life and the cost of these systems. However, substantial further progress remains to be made for this technology to be viable in heavy duty applications.

- Compressed Natural Gas (CNG), Liquefied Natural Gas (LNG) and Biofuels: As more efficient engines utilizing lower emission fuels such as Compressed and Liquefied Natural Gas and biofuels, the opportunity exists for a force multiplier effect by combining the efficiency of a hybrid system with the petroleum offset and CO2 reduction of these cleaner fuels. ■