Increased Transit Efficiency Enables New Era of Solar-Powered Vehicles

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Introduction

With the first solar-powered cars being commercialized, any increases in energy efficiency increase the market and capabilities of solar-powered vehicles, including solar-powered trucks and railcars. Significant increases in efficiency and solar energy collection can lead to an entire new era of solar-powered transit. New ground-effect flight transit (GEFT) vehicles are capable of cutting energy usage in half and doubling the solar energy collection area enabling solar-powered trucks, railcars, and aircraft, setting new standards in efficiency and low-cost operation.

GEFT designs reduce aerodynamic drag to lower levels than otherwise possible and provide aerodynamic lift as a bonus in that transition. Designs target a replacement of 95% of wheel suspension with aerodynamic lift, eliminating 95% of rolling losses. Rolling losses are generally similar in magnitude to aerodynamic losses for streamlined vehicles [1]. Designs resemble sportscar race cars with lower cavity skirts along the sides and a spoiler, however, the spoiler is at the rear of the underbody as a flap and creates higher pressures rather than suction on the underbody.

The Technology - Advances in the energy efficiency of cars and trucks have traditionally focused on reducing aerodynamic drag losses with little attention paid to reducing mechanical losses such as rolling losses. These rolling losses often exceed aerodynamic drag as vehicles become streamlined. A patent-pending vehicle design (see Figure 1) simultaneously: a) further-reduces aerodynamic drag, b) eliminates most of the rolling losses, and c) implements solar-panel laminate upper surface with increased collection of solar energy. The capabilities are a less-than-obvious sequence of phenomena.

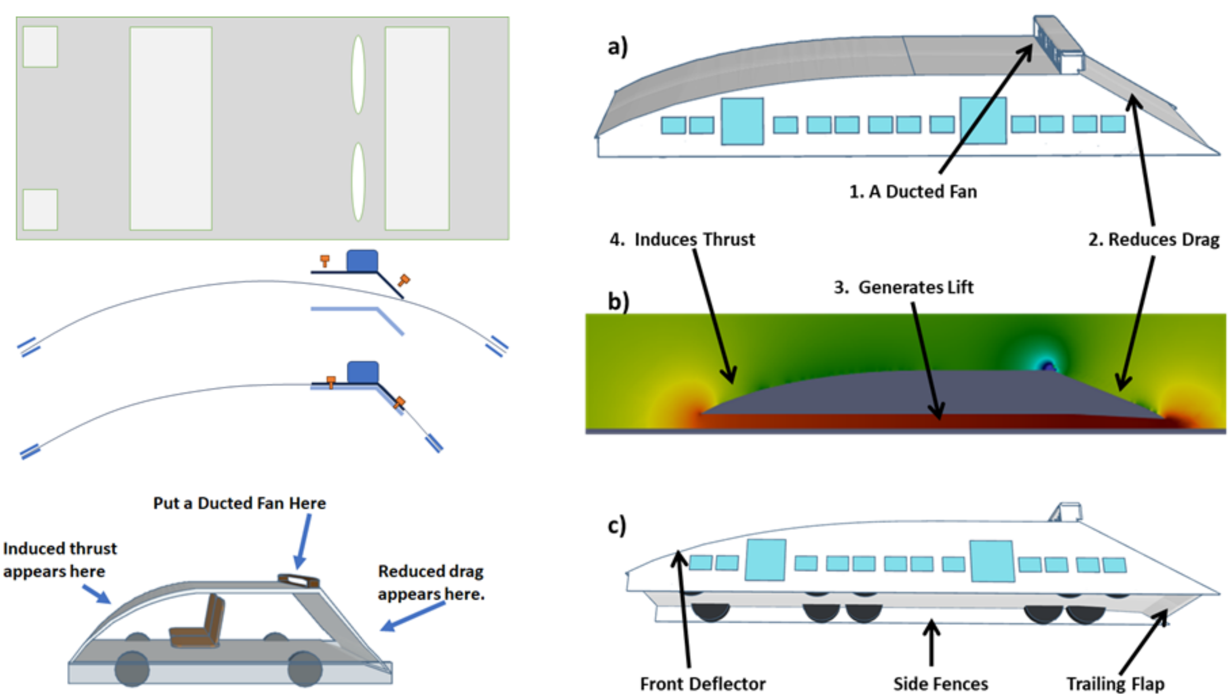

Figure 1. Illustration of four ground effect vehicles using single-laminated-sheet upper-surface fabrication (left) with example vehicle and pressure profile (right). Higher pressure on the lower surface (red) is aerodynamic lift due to air's oncoming dynamic pressure.

The sequence of phenomena include:

1. An upper-surface trailing-section ducted fan pushes air over a trailing taper which reduces form drag which forms on alternative designs.
2. The air flow over the trailing taper impacts the ground and undercarriage flow creating higher pressure at the trailing-edge stagnation point.
3. Higher pressures expand forward through the lower compartment with side fences (aka skirts) reducing lateral dissipation of higher pressures.
4. When the higher pressures reach the vehicle's leading edge, the pressures "push" more air flow up and over the vehicle increasing the region of lower pressures on the front deflector.

Advantageous synergies emerge within the Figure 1 GEFT design, including:

- An upper surface that is one laminate photovoltaic sheet provides a contiguous streamlined surface, displaces upper body fabrication materials with a solar laminate, and provides a high area for solar energy collection.
- The ducted fan's lower pressures reach the front deflector to create induced thrust in the same design that reduces induced drag at the back of the vehicle.
- The same features that reduce drag, also, generate aerodynamic lift which reduces mechanic and rolling losses.
- The ducted fan allows a steeper trailing taper without major increases in drag from turbulence. The trailing taper at a steep 45° to 30° makes the vehicle length more reasonable, lessening the distance higher pressure at the trailing flap need to extend forward to the leading edge.

Table 1 summarizes the type and source of energy savings possible with this technology.

Table 1. Engine power balance, loaded class 8 tractor trailer with benchmark urban and highway data from Canadian Transport[1].

Source	**Urban**	**Highway**	**GEFT**
Drivetrain	10-15%	5-10%	<5%
Inertia/braking/grade	35-50%	0-5%	0-5%
Rolling Resistance	20-30%	30-40%	<5%
Auxiliary Loads	15-20%	2-10%	2-10%
Aerodynamic Losses	10-25%	35-55%	<20%
Savings			>60%

The GEFT technology is a result of rapid innovation initiated in January of 2024 when use of computational fluid dynamics (CFD) was initiated to better understand why improved lift-drag efficiency (L/D) was not achieved in HS-Drone's early aircraft designs. CFD was used to understand performance rather than to refine designs. As a result, an "airfoil science including causality" was developed [2]. Unlike previous theories of aerodynamic lift which identify that pressure is a result of some ambiguous force like the Coanda Effect, the following Three Principles were identified:

1. Impacting air creates higher pressures.
2. Diverging air creates lower pressures.
3. Air expands from higher to lower pressure at the speed of sound.

The expansion from higher to lower pressure at the speed of sound is rooted in the molecular theory of gases where the speed at which a higher density expands to lower densities is related to the translational speeds of molecules which is essentially the speed of sound in gas phases. The reason why

HS-Drone's early aircraft designs did not achieve higher L/D was that lift pressures rapidly dissipated in vertical directions. The solution was to focus on ground-effect flight where the ground blocks downward dissipation of lift pressures under the vehicle. An emphasis was placed on ground-effect flight where L/D values were very high and two observations emerged: 1) much of the technology had been indirectly validated in sportscar racing where fences/skirts are used to stop dissipation of favorable undercarriage pressures and 2) the low-hanging fruit for rapid advances was to focus on reducing rolling losses and keeping wheels on the ground to avoid FAA regulation hurdles [3].

From Box Truck to GEFT - CFD studies toward applying GEFT technology to a box truck are summarized by STL models in Figure 2 and by pressure and velocity profiles in Figure 3. The studies include a progression of adding a forward deflector in an aerodynamic nose, a trailing taper, and a lower surface cavity, followed by a GEFT design for comparison and modified GEFT for wheeled ground transit. CFD profiles are summarized by Figure 3 with performances summarized by Table 2.

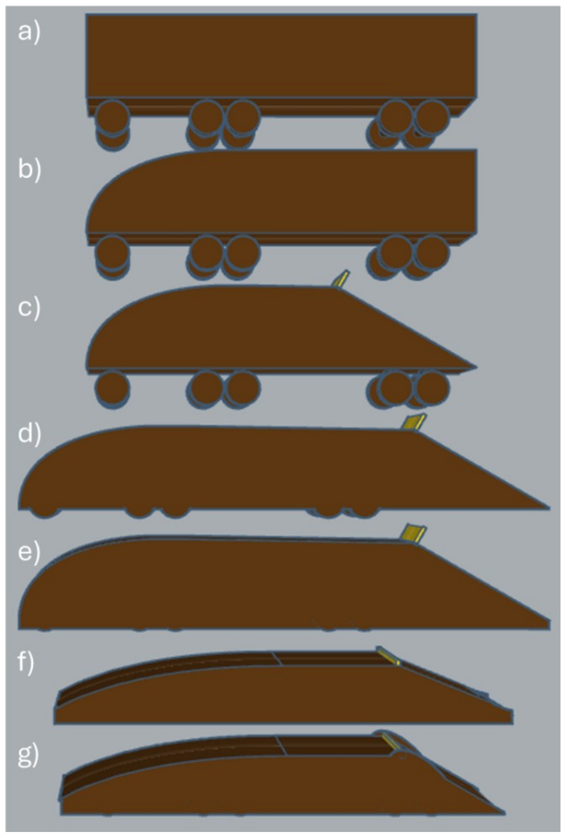

Figure 2. STL images of box truck configurations. From top to bottom: a) Box configuration, b) Aerodynamic nose, c) Trailing 30-degree taper and Sourcebox, d) Extended trailer with 30-degree taper, Sourcebox, and 0.1 clearance on body, and e) fence of 0.02 clearance added to d with i: no flap and ii: trailing flap at 60% of fence extension, f) GEFT comparison design, and g) GEFT with trailing taper fence and wheels.

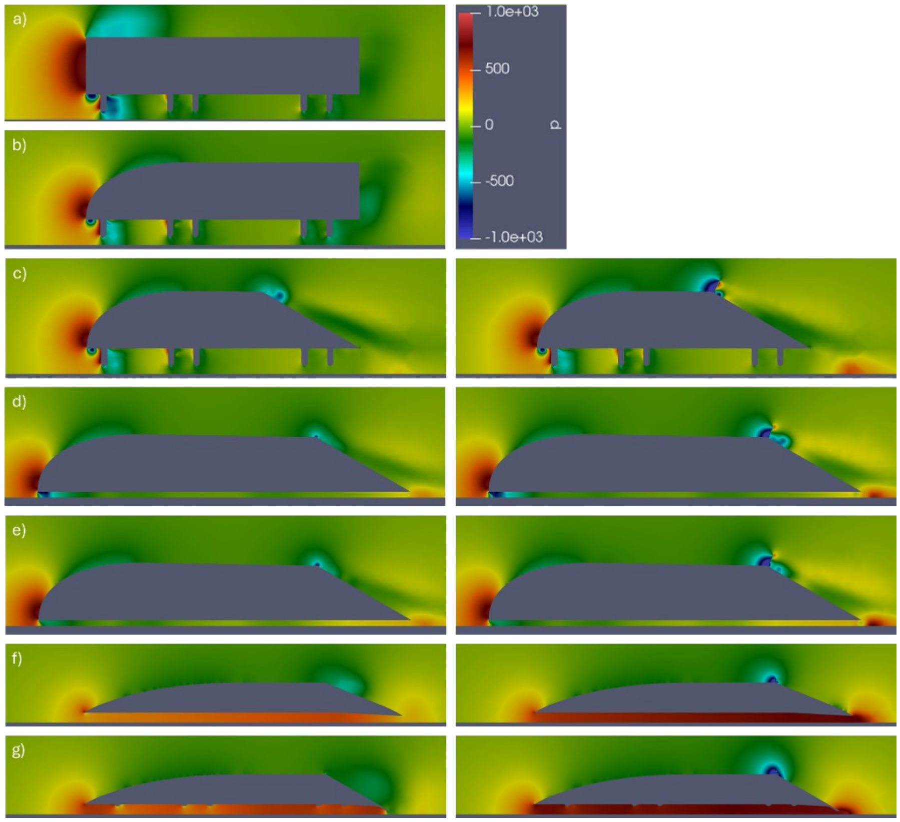

Figure 3. Pressure profiles for box trucks and GEFTs of Figure 2. Left column: No active source. Right column: 5 Source at 30 degrees aligned with tapers (only for trailers with tapers: c-e); 2.5 Source horizontal flow for GEFT (f ang g). (a)-(c) are 0.84m in length, (d) and (e) are 1.17m in length, (f) is 1m in length, and (g) is 0.97m in length. Travel is 40m/s. Source is 4mm by 0.4mm for box trucks and 1mm by 0.5mm for GEFT.

Table 2. Specifications and coefficient of drag data for box truck pressure profiles of Figure 3.

Trailer	Source Power	Cd	Cd viscous	L/D	Aspect Ratio
a) Trailer1_block	0	0.263	0.0083	0.263	0.16
b) Trailer2_nose	0	0.187	0.0170	0.187	0.16
c) Trailer3_Taper	0	0.186	0.0146	0.186	0.16
d) Trailer4_0.1CR	0	0.081	0.0110	0.081	0.12
e) i. Trailer4_0.1CR_Fence	0	0.081	0.0121	0.081	0.12
f) GEFT_Fence_at_0.01CR	2.5	0.037	0.0204	25.4	0.2
"	0	0.034	0.0092	17.0	0.2
g) Wheeled_GEFT_Fence0.01CR	2.5	0.055	0.0090	18.6	0.2

The Figure 3 and Table 2 data on the box truck are decisive on the importance of both the fence and the upper-surface trailing duct fan to create lift and reduce drag. Without the cavity fences, pressure dissipates out the sides of the vehicle and less lift is developed.

Matching Solar Power with Load – The first referred journal paper on this topic emphasized how the GEFT design can be applied to trucks to simultaneously reduce energy consumption and increase the area for solar power collection [4]. The paper identified that when the design is combined with reducing specific loads on trucks, optimal conditions could allow trucks to be fully powered with solar panels on the upper and side surfaces. An extension of those initial calculations is based on matching solar power with load.

Simulations of GEFT identify that the lift forces are primarily on the lower surface with pressures approaching air's dynamic pressure. Table 3 summarizes the values of air's dynamic pressure, which is a function of the speed of the car relative to oncoming air.

Table 3. Air's dynamic pressure at density of 1.25 kg/m^3, car width of 8.5 ft. The power depends on the L/D efficiencies which is set at 20 for a 6' high truck at an aspect ratio of 0.2.

U	U	Pa	Load	Power
(m/s)	mph	kg/m/s^2	lb/ft	W/m^2
20	45	248	44	248
30	67	563	100	845
40	90	1000	178	2000
50	112	1563	277	3910

At lower velocities, more of the weight rests on the tires. The L/D is not a strong function of velocity, and so, the power needs are proportional to velocity. For sunny days, solar power can be collected at about 250 W/m^2, which means that direct solar power can fully sustain travel at 45 mph. Batteries can be charged when parked or at charging stations to sustain higher speeds. Higher speeds are possible with increases in surface area for solar power, higher aspect ratio vehicles, and with improvements to photovoltaic cells. Optimal vehicle designs would reduce battery weights and costs for car bodies fully covered with solar cells. Direct solar cars and trucks are viable in the near term with 60-70 mph for ultra-light GEFT designs at conditions leading to L/D in excess of 30, with modest advances in photovoltaic cell efficiency, and with use of photovoltaic cells on upper and side surfaces.

Operational Logistics - Figure 4 identifies an expanded approach to increase solar power collection and increase the extent to which solar power may be used in trucking.

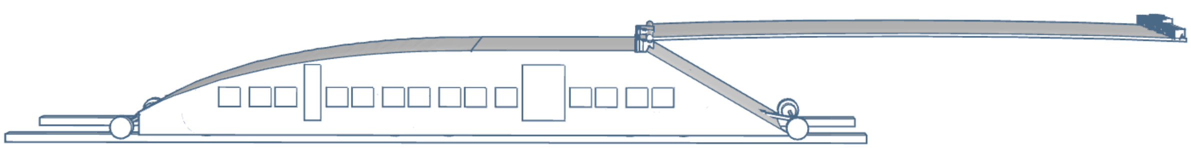

Figure 4. Hi-Rail (highway-rail) vehicle with extendable solar sheet platform.

Applications pushing solar-powered viability become viable in wide markets when considering:

- extendable solar-powered sheet platform technology of Figure 4,
- the continuously increasing photovoltaic cell productivity, and
- vehicles with higher aspect ratios (width divided by length) and lower thickness ratios (height divided by length) leading to higher L/D efficiencies and targeting sustainable solar power for vehicles as the primary driver.

By example, reducing the height of a truck from 2.1 m to 1 m would enable L/D efficiencies in excess of 30. As many states face mandates on the implementation of electric trucks, the GEFT technology emerges as a means to take electric trucks to a higher sustainable level where battery, vehicle, and energy costs can be substantially reduced relative to alternatives.

When the sun sets, so does direct solar power. However, as autonomous vehicle trucking technology emerges it will become increasingly acceptable for trucks to park when the sun goes down and restart the journey with the next day's sun.

Solar-powered and electric trucking is debatably the most challenging implementation of road, rail, air, and water corridor solar transits since trucks are restricted by road width and do not ride over the smooth upper surface of rails that allow for lower fence-rail clearances to enable the highest L/D. Alternatively, delivery vehicles which are typically parked or operate at lower cruising speeds would benefit from solar charging while stationary.

Over water, greater widths and heights can be used advantageously to achieve both higher efficiency and disproportionately higher increases in area for solar power collection. Also, the large inner areas of catamaran-type ship designs may be redesigned as single-laminated sheets which collect considerably more incremental energy than needed sustain their incremental increases in mass.

Optimal Operational Conditions – The worst-case scenario for solar-powered vehicles is stop-and-go traffic where cruising speeds in excess of 50 mph rarely achieved. Large sections of interstate highways regularly sustain transit at cruising speeds in excess of 50 mph; the sections in regions of high irradiance would be ideal markets for GEFT solar-powered trucks.

Railways are potentially good markets. Railway tracks supplement blocking lateral losses of lift pressures; it is anticipated that sustained operation clearances of less than 1 cm are possible with railcars.

The U.S. has fallen behind other countries in highspeed trains, maglev, and hyperloop development. China and Japan have emerged as world leaders on maglev technologies with operational commercial lines. High speed trains typically weight 300 to 500 tons, requiring expensive, robust tracks with gradual turns to handle travel at 200 mph. Maglev trains may weigh less but require continuous and expensive new tracks [5-7].

GEFT is able to achieve high speeds on existing lower tolerance tracks throughout the world by traveling on a cushion of air with minimal weight utilizing rubber tires. Example weights of GEFT are 150 lbs. per ft of length. At 85 mph, a 40 ft railcar supporting about 20 passengers would weigh 3 tons. Both suspension and turning are be based primarily on aerodynamics acting on the body, flaps, and ailerons—not on the rails. Railway track infrastructure is available between and throughout all major cities. This is particularly useful for the U.S. as the expansive distance between cities is exponentially more expensive for high-speed rail and maglev track implementation and maintenance, while these technologies will use already developed infrastructure at greater efficiency.

The greatest advantage of GEFT goes beyond what has even been considered for highspeed trains and maglev. GEFT may travel in close proximity as train units where the trailing cars stop at stations while the rest of the cars continue [8]. Similarly, stopped GEFT cars can depart stations ahead of an incoming train to dynamically take the train's lead positions. This approach is illustrated by Figure 3.

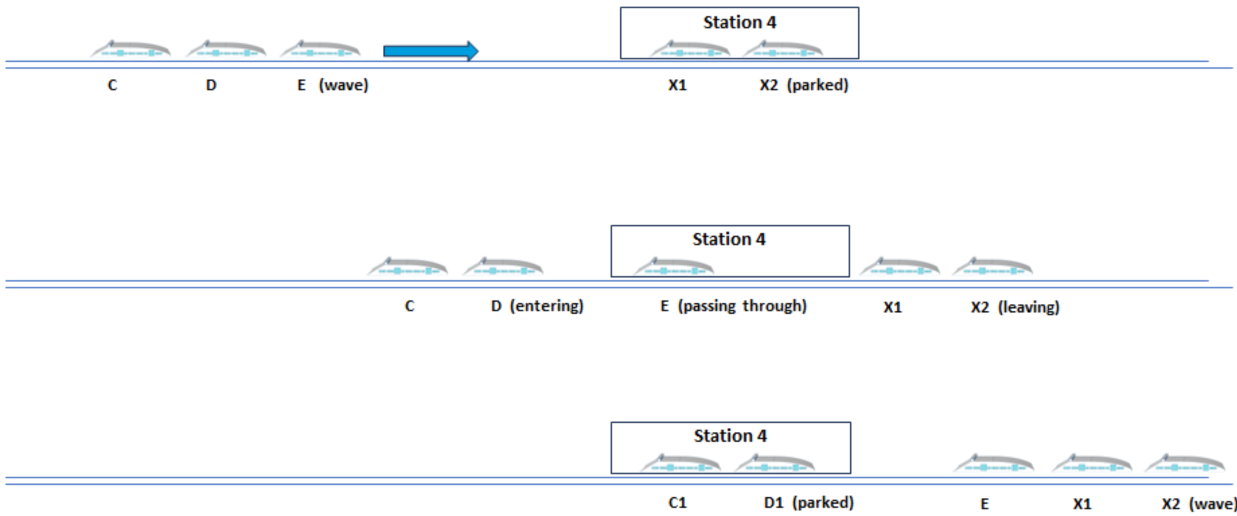

Figure 3. Illustration of operation of stations where cars parked at stations take lead positions in dynamic trains while trailing cars of the train stop at the stations.

Operation is compatible with freight transport and high passenger capacity by using initiating "dynamic waves of trains" with trailing cars stopping at stations. Tires would allow cars to turn around at locations without rails that would otherwise not accommodate reversal of direction; this strategy would allow the transit capacity to vary along a railway track to improve service and better use passenger car capacities.

By changing the length of the dynamic trains, the number of stations a car bypasses between stops is modified, which enables nonstop service between each pair of stations on a service line. Operating the GEFT nonstop on rails cut transit times considerably. If higher speeds are enabled with battery supplements to solar power, the times and costs of transit would be cut by more than half. When applied on a global basis, the annual value is multiple trillion dollars per year from the money saved value of time. The value is greater if the rail system replaces car costs, including parking and insurance.

The multi-trillion-dollar annual impact is based only on commuter transit applications. Intercity transit can displace air transit without the time and costs of going through airports yet providing similar transit speeds. Freight and parcel transit can be intermixed with passenger transit for larger markets to replace some trucking and the related diesel fuel consumption. The capabilities continue to expand with rail/road/water multimodality which are ultimately faster and lower cost than air transit due to seamless accessibility to the massive railway, roadway, and port infrastructure.

New Infrastructure – Solar-powered GEFT could be used on infrastructure to make major strides to a zero-carbon-footprint society while reducing transit costs and increasing quality of life. The characteristics of GEFT teach toward vehicles which are multimodal, able to routinely transfer between rail and highway corridors. In this mode of operation, it is strategically advantageous to expand that infrastructure using railways.

GEFT efficiency is particularly high with two pairs of fences defining the lower cavity. An inner pair is consistent with engaging the common railway gauges. An outer pair would engage either the outer edge of railway ties or an outer smooth surface parallel to the inner rails. New infrastructure would preferably have the following characteristics:

- An inner pair of rails and an outer parallel surface for engaging outer fences on GEFT.
- A lower cost track/corridor design matching the lighter vehicle designs of GEFT which are absent the heavy bodies of train cars and use light weight construction common to aircraft.

- A continuous corridor surface that blocks downward losses of lift pressure and is covered with solar panels.

The last bullet teaches toward a massive solar power initiative using dual-purpose materials that create transit corridors and collect solar power. This dual-purpose corridor surfaces are possible since GEFT wheels do not impact the corridor surface; the wheels stay on the tracks.

Concluding Thoughts – The use of ground-effect to provide lift on vehicles provides the high-impact advantage of substantially eliminated mechanical and rolling losses of vehicles which can reduce energy consumption my more than half of the available alternatives. This advance is consistent with increased area for collection of solar power and greatly expands what is possible with solar-powered vehicles.

A cascade of synergies is put in motion by this technology. On the GEFT vehicles, lower aerodynamic drags are possible alongside substantial elimination of rolling losses. The ground-effect flight also enables since railcars to travel in ground-effect flight without destructive interference, and this mode of operation allows dynamically forming trains to be used on railways that can reduce travel times and costs by 50% to 80%.

The technology could be used immediately on existing roadway and railway infrastructure. A final synergy is dual-purpose infrastructure where low-cost solar power laminates would block downward dissipation of lift pressures.

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