

Transportation Solutions Defense and Education Fund

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April 18, 2016
By E-Mail to:
2016businessplan
comments
@hsr.ca.gov

Dan Richard, Chair
California High-Speed Rail Authority
770 L Street, Suite 620 MS-1
Sacramento, CA 95814

Re: Draft 2016 Business Plan

Dear Mr. Richard:

The Transportation Solutions Defense and Education Fund, TRANSDEF, is a non-profit environmental group dedicated to the regional and interregional planning of transportation, land use and air quality. Our focus is on reducing GHG emissions from transportation. TRANSDEF has long been actively involved in HSR, starting with commenting on the Draft Statewide EIR in 2004. We have been a party in all three *Town of Atherton* EIR challenges and the appeal. We continue to be conceptually supportive of HSR, but do not believe the CHSRA's project can be economically viable--or even can be built--due to its being designed to meet priorities other than transportation.

With this Draft Business Plan, the Authority has pretty much admitted there is no way it can build to Southern CA. The \$3.2 billion in projected monetization from the IOS (p. 64) is only a tiny fraction of the cost to complete Phase 1. With no likely sources of additional funding, the situation is grim. This moment requires courageous truth-telling and owning up to past mistakes. This Draft Plan is not that.

The Draft Business Plan repeatedly mentions bringing in the private sector early in the design process. That is what the Peer Review Group recommended. But it is not what was done. The private sector was not brought in for the most critical part of the design: route selection. The reason there is no private money in this project now is because the politically selected route is a money-loser. (Rail operators won't say that publicly for fear of retaliation.) HSR in California could be a moneymaking business if the route is optimized for operating profits, but political considerations and private interests have been foremost ever since CHSRA was formed. The public interest has been subverted.

TRANSDEF urges the Authority to consider the analysis contained herein, and put the project on hold. We continue to believe that the way forward is a Request for Proposals

that invites the private sector to propose their own route, environmentally cleared at State expense. A private sector-led project would have a completely different dynamic, and could potentially secure consensus support in the Legislature and Congress. If the drawdown were to stop immediately, Congress might be willing to reinstate the unused portion of the ARRA grant to a private sector-led project.

We note with dismay the Authority's overt contempt for the public. The complete irrelevance of public comments is evident in its announced adoption date for the Final Business Plan three days following the close of the comment period. We hereby incorporate by reference the 4/18/16 comments of the Train Riders Association of CA.

Initial Operating Segment

It did not help the Authority's flagging public support to put forward an IOS with a southern terminus in an orchard in Shafter. That decision led to news stories on The Train to Nowhere that wrote themselves. While the Chair has indicated that the Final Business Plan is likely to have a different terminus, the executive that signed off on the decision to put it in the draft deserves to be reprimanded for exceedingly poor judgment.

Greenhouse Gas Emissions

TRANSDEF produced an in-depth analysis of the 2013 GHG Emissions paper by CHSRA. (See Attachment 1.) It found many flaws, most notable of which was the failure to include the life-cycle emissions of the construction materials, especially concrete. TRANSDEF filed suit to challenge the Air Resources Board's inclusion of HSR as a GHG emissions reduction measure in the first update to the Scoping Plan. In addition, the suit asks the court to invalidate the appropriation of revenues from the Greenhouse Gas Reduction Fund to HSR. CHSRA is a Real Party in Interest in that case.

On the basis of evidence submitted to ARB (See Attachment 2), TRANSDEF concludes that HSR will be a net GHG emitter for at least the first twenty to thirty years of operations. It makes no sense to use the GHG Reduction Fund to build something that won't reduce GHGs for a long time to come. AB 32 recognized the need to get reductions early, when it can slow down movement towards the tipping point. That's when new feedback loops kick in and catastrophic climate change will become unstoppable.

Six years later, it is time for CHSRA to produce a credible GHG emissions analysis that considers all emissions related to the IOS (because that is the only part of the project that is claimed to be funded), using the ridership cited in the Business Plan. (Parenthetically, TRANSDEF notes its inability to suspend disbelief as to the projected ridership for the IOS. See discussion below.) The analysis should specifically determine which year of operations of the IOS the net GHG emissions will become negative. The study should be conducted by an identified author with appropriate credentials for the task.

Until we are convinced by a credible study, TRANSDEF will continue to assert that the current HSR project will be a net GHG emitter if built, and therefore should not receive cap and trade funds. Without cap and trade funds, it cannot access bond funds, making the project infeasible.

Ridership

The ridership projection from San Jose to the Central Valley seems unreasonably high, at about twice recent San Joaquin Amtrak annual ridership, for a trip that is significantly more expensive. It seems unlikely the market can support the pricing expected for HSR. If the projections based on stated preference surveys are to be believed, the documentation needs to confirm that the survey specifically asked about taking an HSR trip from San Jose to Fresno and a bus to Los Angeles. Asking about an HSR trip to Los Angeles would be irrelevant for projecting IOS ridership.

A brand new marketing direction is offered in this Business Plan: HSR is good for commuting to jobs in the Silicon Valley. This is laughable: The projected \$63 fare each way is not feasible for commuters, especially for people that are commuting because they can't afford to live in the Bay Area. And it is beyond ludicrous to use cap and trade funds to facilitate the construction of sprawl, which greatly increases GHG emissions. The 2005 Statewide FEIR had an inadequate treatment of growth inducement. It offered no meaningful mitigation measures such as incentives to local jurisdictions to make their future land use patterns compact. Disincentives to continued sprawl would be needed if the long-time pattern is to change. There is no legal basis to expect that "effective land use and transit-oriented development" (p. 46) will replace generations of sprawl.

Capital Costs

Public trust of CHSRA's reporting of capital costs hit a new low following the revelation of the secret PB memo. The attempt at damage control was not at all convincing. It appears to informed members of the public that impending large cost increases have been held back. Meanwhile, at least some of the reduction in Phase 1 cost estimates are the result of scope reductions, of which the \$1.5 billion reduction in funding for the Caltrain Downtown Extension is the most evident. Because it is a large enough number to be identified, but was not called out in Figure 1 of the Capital Cost Basis of Estimate Report, it appears that the \$5.5 billion in cost reductions is actually a net figure, masking cost increases in certain SCCs or sections.

TRANSDEF suggests that a productive way to repair the public's trust in the project and its management would be to release a master spreadsheet (in .xlsx electronic format) as a supplement to the Capital Cost Basis of Estimate Report. It would track the cost estimate for each project segment (identified by specific mileposts) through each of the various Business Plans, starting with 2012. Each item for each Business Plan should have a quantity and a unit cost. That way, it will be possible to see exactly what changes from Plan to Plan. In addition, it should be a working spreadsheet with formulas, including those for updating costs for inflation. This would make it possible to verify that the 2014 Business Plan capital costs were in fact the 2012 Business Plan costs, with an inflation adjustment. A thoroughly informative spreadsheet would clarify such things. Where significant changes occur, it would be helpful to have notes keyed to the cells. A dramatic change in the degree of transparency might make the project more credible.

Funding

While the 2016 Draft Business Plan appears to demonstrate the needed full funding for the IOS, that funding is a mirage. It relies on cap and trade funding all the way out to 2050. The expectation is to raise \$5 billion in bonds that are secured by the cap and trade revenues between 2025 and 2050. Those revenues are so speculative that it seems highly unlikely that money on that scale can be raised. Even if it can be raised, it would be very costly, as it would be treated as a junk bond.

It will also take several acts of the Legislature that are bound to be highly controversial: extending the life of cap and trade, putting funds into reserves to pay back the bonds, and pledging considerably more than HSR's 25% share of the funds. Without all the projected cap and trade funds, no pre-expenditure funding plan can qualify for bond funds. Without bond funds for construction, the HSR project cannot proceed. CHSRA will have to go out of business once the federal grant is spent.

Bookends

Bond funding for local projects in the north and south, known as the Bookends, cannot be released for construction. These projects include such projects as Caltrain electrification and grade separations in Southern California. Despite the Legislature having appropriated bond funding for them, they do not qualify for construction funding. To get the funding, a project would have to be part of a fully funded and environmentally cleared segment that will result in infrastructure that is HSR-ready and whose operations will be self-supporting financially. The Bookends can't pass these tests.

Urban Areas

In his April Senate Committee testimony, Chair Richard said trains would go 120 MPH through urban areas, presumably to lower the noise emitted by trains. However, it won't be possible to make the required travel time at that speed. Please show how you can keep the speed down and the speed up at the same time. Contrary to a statement made by HSRA communications staff, San Jose is not the heart of Silicon Valley.

Comments on Specific Pages

4. Where is the information on the estimated capital costs for each segment of the statewide high-speed rail system under PUC 185033(b)(1)(A)?

9. Cap and Trade funds are placed in the Greenhouse Gas Reduction Fund. They are not Greenhouse Gas Reduction Funds.

10 & 11. Cost estimates are not directly comparable. Some lower cost estimates are the result of downscoping. e.g., Elimination of \$1.5 Billion contribution to DTX.

12. Please provide ridership breakout by destination to enable evaluation of the significance of commuter traffic, the credibility of the long-distance estimates and the potential impacts of induced sprawl.

12. Investment of public dollars may be the predicate for private sector investment, but without private sector involvement in route selection, the risk is too high that the private sector will never get involved, leaving a stranded asset. The current HSR project is a political deal and not a transportation project.

30. The structure of 1A is intended to prevent the expenditure of funds that could result in a segment that is not complete. The ICS managed to escape that fiscal discipline, but will not escape it in the future, should there be an attempt to use the bond funds.

31. So far, the HSR system is entirely a public works project. As stated on p. 35, it is government owned and constructed, based on government decisions.

32. In seeking to achieve zero GHG emissions construction, the full lifecycle emissions of the materials used in construction must be included. They were not included in the 2013 GHG analysis done for the Legislature.

35 & 36 & 38. Bringing in an operator after the route has already been selected is far too late, if the intent is to have significant private sector investment.

39. The train operator needed to be involved in the most important planning decision: the route. It is insulting to the public to claim that the train operator must be at the forefront of business model development, when the political process distorted the route selection so badly as to make the project infeasible.

40. The key decisions most important to the private sector have already been made. The likelihood of getting future investment is small, because the route can be expected to perform poorly. Adequate ridership is very unlikely.

45. The logical way to secure private sector participation would have been to offer rail operators the ability to propose their own routes, with the assumption of ridership risk. Instead, CHSRA proposes to place 100% of the risk of the first \$21 billion on taxpayers. The Authority refused to consider route flexibility on an unsolicited proposal by SNCF America, which had the investment banking support to build the San Francisco-Los Angeles system. (See http://transdef.org/HSR/Private_Capital.html)

45. The assertion that HSR "will enable people to work at high-tech jobs in the Silicon Valley and San Francisco while having greater access to more affordable housing options in Central Valley..." is inconsistent with HSR as a profit-making business. Commuting is only viable with a subsidized public transit business model, because HSR is far more costly.

49. See above for a discussion of the packages of projects.

49. Greenhouse gases are not criteria pollutants that cause human health impacts. The cumulative global GHG emissions cause climate impacts, not direct health impacts. As a result, there is no relief provided to disadvantaged communities.

50. The Santa Fe Springs triple tracking may provide benefits to Amtrak and Metrolink, but isn't HSR supposed to have dedicated tracks here?

56. The cost estimate only covers access to 4th and King in San Francisco, which is not the terminus of the system. What is the total cost of Phase 1 to the Transbay Transit Center?

75. Does the inflation in O & M costs in Exhibit 7.16 portend future problems with ridership? The ridership model documentation is silent on whether this degree of inflation could eventually affect demand. It should not be assumed that price elasticity

remains constant. At some fare point, the elasticity has to hit a breaking point, resulting in a death spiral.

88. It would be appropriate to identify the program level risks of 1). the invalidation of cap and trade by the courts; 2) the invalidation of the HSR appropriation of cap and trade by the courts; and 3). the Legislature's inaction on extending cap and trade, and providing the necessary framework to enable securitization, which is the foundation of the Business Plan.

89. A major risk that remains unidentified is the absence of a regulatory structure for implementing 25 kv. overhead power on blended systems. There cannot be a Phase 1 without these rules, yet no proceeding is open at the CPUC.

89. The mitigations listed for declining shareholder support are unlikely to be effective. See transparency suggestion, above.

92. CHSRA petitioned STB for the preemption of CEQA. This should be listed as environmental risk mitigation. The uncertain future of preemption, on appeal both in federal court and in the California Supreme Court, is a risk that needs to be identified.

92. A major risk that remains unidentified in the Business Plan is the trackage right Union Pacific RR has on the Caltrain ROW. UP will have to give its permission for CHSRA to provide intercity rail service in the Corridor. Until an agreement is in place, CHSRA needs a fallback plan. We believe the fallback should be obvious, given TRANSDEF's past litigation.

Conclusion

In these comments and in the previous twelve years of advocacy, TRANSDEF has provided constructive suggestions for how to achieve a functioning and profitable HSR system in California. As we have continuously predicted, due to its non-viable business model, CHSRA is about to run out of money. TRANSDEF is always willing to meet with CHSRA staff and/or Board to assist in changing direction.

Sincerely,

/s/ DAVID SCHONBRUNN

David Schonbrunn,
President

Attachments

1. Analysis of the CHSRA's GHG Report. TRANSDEF. 2014.

2. High-speed rail with emerging automobiles and aircraft can reduce environmental impacts in California's future. Chester, M. and Horvath, A. Environ. Res. Lett. 7 (2012) 034012.

Attachment 1

Transportation Solutions Defense and Education Fund

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Analysis of the CHSRA's GHG Report

On July 1, 2013, the California High-Speed Rail Authority released its *Contribution of the High-Speed Rail Program to Reducing California's Greenhouse Gas Emission Levels* (June 2013).¹ It is meant to fulfill the mandate contained in SB 1029 (the Legislature's authorization of HSR bonds for the Central Valley project) to provide "a report on the 'net impact of the high-speed rail program on the state's greenhouse gas emissions.'"² However, the report fails to quantify the project's emissions and emissions reductions, thereby making an evaluation of the program's net impact impossible.

The report is obviously intended to counter the Legislative Analyst's budget report³ of April 2012, which concluded that the HSR project would result in a net increase in GHG emissions for the first 30 years of operations. Knocking down that report would open the door to funding HSR with cap and trade revenues. Interestingly, the CHSRA report never mentioned the LAO report and pretended it didn't exist. Someone must have concluded they couldn't win an argument on the merits.

Rather than dispute the LAO report, the CHSRA report claims to "detail[] the projected net greenhouse gas (GHG) emissions associated with the construction and operation of the high-speed rail system."⁴ However, the report offers no details of those emissions. If numbers were developed during the preparation of the report, they weren't included in the publication. This is a politicized promotional piece and not a science-based document. It is simply not credible and not responsive to the legislative mandate.

Update: The Governor's Budget Proposal

The Governor proposed that \$250 million in 2014-15 cap and trade revenues go to HSRA. He further requested that 33% of all cap and trade revenues starting with 2015-16 be continuously appropriated to HSRA.⁵ These many billions of dollars, if not well-spent by the HSR project, could threaten the effectiveness of the entire cap and trade program. Careful scrutiny of the HSR project's net GHG benefits is warranted.

Methodology

A disclosure on p. 17 invalidates the entire report: "The timeframe and activities analyzed and discussed in this report were for CP1 [the first phase of the current Merced-Bakersfield project]. As the project moves forward, direct GHG emissions calculations will be carried out for each subsequent construction package." The construction impacts of CP1 cannot be meaningfully analyzed in relation to the operational emissions

reductions calculations, because the latter pertains to the Initial Operating Section (IOS), which is ten times its length. No HSR operations are planned for CP1.

This is critical, because the report is actually comparing the emissions benefits of the IOS to the emissions costs of the one-tenth-as-long CP1. Completing the IOS would require funding the \$26 billion extension to the LA Basin, as well as building CP2, CP3, CP4 and CP5 [the remainder of the Merced-Bakersfield project]. Obviously, the net project emissions are going to be very different when the emissions arising from \$26+ billion of construction are added in.

Evaluating the HSR program's net impacts requires either the operational emissions reductions of CP1 or the construction emissions of the IOS. This report offers neither.

Summary of Findings

The following six so-called Findings are mere restatements of vague intentions, with no identified funding to implement them:

- Commitment to 100% renewable energy during operations
- Zero net greenhouse gas emissions during construction
- Supportive transit and land use for greater cumulative benefits for the state
- Plans to plant thousands of new trees across the Central Valley
- Cleaner school buses and water pumps in Central Valley communities
- Agricultural conservation measures aimed at reducing Central Valley sprawl and preserving valuable agricultural land⁶

In addition, the report offers no evidence in support of the following two so-called Findings:

- Zero net greenhouse gas emissions during construction⁷

There is no evidence to support this claim. No numbers whatsoever are offered for GHG mitigation activities. This is a classic "aspirational goal" rather than a finding on a plan to achieve one.

- Significant contributions to the State's goals embodied in AB 32 and SB 375⁸

There is no evidence to support this claim.

Not only is there no evidence to support the following three so-called Findings, they are actively misleading, as they are entirely dependent on CHSRA receiving an additional \$26 billion to build out the IOS to the Los Angeles Basin. In addition, they will mislead non-technical readers because they appear to be findings on the project's net emissions impacts. Because they exclude the construction emissions of both CP1 and the IOS, they represent only one side of the emissions ledger.

- Greenhouse gas savings from the first year of operations increasing to over 1 million tons of CO2 per year within 10 years⁹
- Result in net GHG emissions diversions that, conservatively, are the equivalent of the GHG emissions created from the electricity used in 22,440 houses, or removing 31,000 passenger vehicles from the road.¹⁰

- Using methodologies consistent with state practice, an estimated 4 to 8 million metric tons of CO₂ saved by 2030, as if the state turned off a coal fired power plant¹¹

As discussed below, this last assertion is also misleading because the 8 years of operations are being compared to roughly one year of such a power plant's emissions.

GHG Emissions Sources for High-Speed Rail System

The diagram on page 9 is the only rendition of emissions category totals in the report. Amazingly, there is no corresponding table. The diagram comes closer to identifying the net impact than anything else in the report. However, its use of graphic symbols instead of conventional chart bars makes it impossible to interpret quantitatively. It is unclear from the diagram (or its associated text) whether the symbols have any quantitative significance, and if they do, whether emissions totals are represented by the height or by the area of the symbols. This makes the diagram both useless and deceptive: it obscures more than it discloses. Given the central importance of this data, choosing this indecipherable diagram for its portrayal can only be interpreted as an act of bad faith.

Operational Emissions Reductions

This project has had a long history of challenges to the technical validity of the HSR ridership model and litigation about the hidden changes that were made to it that advantaged Pacheco ridership while penalizing Altamont ridership. Ridership is the key input to an analysis of operational emissions reductions. As will be discussed later, the GHG reduction benefits of the HSR project are very dependent on ridership. With the controversy surrounding the ridership projections, this net emissions analysis rests on a shaky foundation.

The most striking part of this section is the meaningless apples-and-oranges comparison between the annual emissions of a coal-fired power plant and the emissions reductions from 8 years of HSR operations.¹² This is an attempt to invite positive identification with HSR by creating a "Coal Bad--HSR Good" dualism, a classic technique of promotion.

Construction Emissions

While the report uses standard methods to calculate the direct emissions resulting from construction, it entirely leaves out the emissions resulting from the acquisition of construction materials, and offers a weak justification that these emissions shouldn't be counted against the project:

Regarding the construction materials, for some it is possible to calculate the impacts over the material's life-cycle, from extraction through processing, use onsite, and disposal, and express those impacts in GHG emissions terms. Those GHG emissions are usually the reporting responsibility of the manufacturer, and in terms of a project GHG emissions

inventory, happen "upstream" and outside the boundary of the project.

For example, cement manufacturers in California are subject to ARB's Mandatory Reporting and Cap-and-Trade Regulations. These regulations require cement manufacturers to report their GHG emissions annually to ARB. The emissions from cement manufacturing count towards the statewide GHG emissions "cap." The GHG emissions covered under the "cap" are required to be reduced through emission controls or a limited amount (eight percent) may be offset through the purchase of ARB certified offset credits.¹³

The problem is that these emissions from construction materials constitute a very significant part of the project's overall emissions, because of the huge amount of concrete called for in the plans. This amount is large enough to increase the cement manufacturing sector's statewide emissions, which makes the "count it upstream" approach entirely inappropriate when evaluating the project's net impacts.

Perhaps recognizing this, the next paragraph of the report acknowledges the appropriateness of including the emissions from construction materials in its analysis, yet withholds the data on the flimsy excuse that the data is not "precise" enough:

However, the Authority considers it important to disclose the GHG emissions that occur outside of the project associated with materials used during construction. **These have not yet been quantified, due to the limitations of available information at this stage of project delivery.** While it is understood that the rail infrastructure will consist, largely of aggregate, concrete, steel, rails, and ballast; the **precise** source and supplier of those materials is not yet known. Additionally, the **precise** quantities are not available, given the nature of the design-build procurement process... (emphasis added)¹⁴

This is a masterful exercise in appearing to be fair-minded while simultaneously holding back damaging information. It is obvious that in the course of putting the project out to bid, the Authority prepared estimates of construction material quantities. These estimates were the basis for the calculation of the direct construction emissions. The materials' emissions must be **huge** for the Authority to need to bury them with this kind of double-talk.

The Legislative Analyst's April 2012 report¹⁵ relied on a 2010 pioneering study by Chester and Horvath entitled *Life-cycle assessment of high-speed rail: the case of California*.¹⁶ The study's 2012 update produced data that enabled this calculation: Infrastructure construction and operations contribute between 40% and 51% of the

CHSRA project's GHG emissions per person per kilometer travelled. This figure rises to near 100% of the emissions for the scenario with 100% renewable power, and falls to 32% when the train's capacity is nearly doubled.¹⁷ The paper found "CAHSR infrastructure construction effects are dominated by concrete use. Approximately 67% of CAHSR infrastructure emissions are the result of cement production for concrete use..."¹⁸

This is the smoking gun: Construction materials (as well as infrastructure construction, if one doesn't assume the success of the zero net GHG emissions program¹⁹) make up a highly significant percentage of the project's overall GHG emissions. Leaving them out so compromises the net impact analysis as to render it worthless.

The Chester and Horvath study calculated the project's payback period, the point at which the emissions reductions from the substitution of auto and air trips (measured as Vehicle Kilometers Traveled, or VKT) with HSR trips equals the HSR project's GHG emissions, including its cumulative prior emissions:

The payback sensitivity reveals several important considerations for transportation planners and air quality policy makers. The cumulative plum-colored lines for the high, medium and low forecast figures show that the **GHG payback will likely occur between 20 and 30 yr (D3) after groundbreaking**, and acidification potential after 20–40 yr. **However, payback is highly sensitive to reduced automobile travel.** The 5.8 billion auto VKT displaced dominate emissions changes in the corridor and the effects from reduced air travel and CAHSR are small. The reduced auto impacts are significantly affected or dominated by life-cycle components, in particular, avoided vehicle manufacturing, vehicle maintenance and gasoline production. (emphasis added.)²⁰

Chester and Horvath are thus warning that any slip in ridership from currently predicted levels would delay the GHG benefits of HSR even further.

Double Counting

When evaluating statewide benefits, it is important that GHG emissions reductions calculations represent only the project's own properties. The model that was used, on the other hand, "also reflects the GHG emissions benefits of ARB's recent rulemakings including on-road diesel fleet rules, Pavley Clean Car Standards, and the Low Carbon Fuel standard."²¹ This means that the report's emissions reduction calculations overstate the benefits accruing to the HSR project.

Offset Activities

The only way the CHSRA's GHG Report is able to claim a net beneficial GHG impact is by buying offsets in the form of environmental mitigations, including construction mitigations,²² and farmland protection.²³ The strategy of the Cap and Trade program is

to purchase GHG-reducing offsets at the lowest cost per ton. There's something very odd about committing Cap and Trade funds to a project that increases GHGs, which then has to buy GHG-reducing offsets. It would be dramatically less expensive on a per-ton basis to fund the GHG-reducing projects directly. Buying these same offsets as part of a CHSRA project package is inherently far more expensive.

Conclusion

The report offers no numbers capable of serving as a basis for the conclusion that "the high-speed rail program will have a positive impact on reducing the state's greenhouse gas emissions."²⁴ Instead, that conclusion "'feels right' without regard to evidence, logic, intellectual examination, or facts"--the Wikipedia definition of Stephen Colbert's 'truthiness'.

Endorsements

The uncritical endorsements of the report by agency heads expose the depth of its politicization. It simply is not credible that sophisticated agency heads and their staffs failed to spot the profound flaws identified above. Brian Kelly, now Secretary of the State Transportation Agency, "reviewed and approve[s]" the report.²⁵ Mary Nichols, Chair of the Air Resources Board, "believe[s] the analysis is reasonable..."²⁶ Instead of the comprehensive overview expected of someone of her subject matter expertise, she offered only superficial comments on the emissions reductions from mobility choices, and avoided construction emissions and offsets entirely. These two endorsements make it obvious that the Governor ordered his people to "make HSR funding happen" no matter what.

¹ hsr.ca.gov/docs/programs/green_practices/HSR_Reducing_CA_GHG_Emissions_2013.pdf

² p. 13. (Unless otherwise noted, all references are to the report accessible at the URL above.)

³ Legislative Analyst's Office, *Funding Requests for High-Speed Rail*, April 17, 2012, p. 8

⁴ p. 13.

⁵ Legislative Analyst's Office, *Cap-and-Trade Auction Revenue Expenditure Plan*, February 2014, p. 5

⁶ p. 6.

⁷ *Id.*

⁸ *Id.*

⁹ *Id.*

¹⁰ *Id.*

¹¹ *Id.*

¹² p. 11.

¹³ p. 14.

¹⁴ p. 14.

¹⁵ Legislative Analyst's Office, p. 8

¹⁶ Mikhail Chester and Arpad Horvath, *Life-cycle assessment of high-speed rail: the case of California*, Environmental Research Letters, January 2010.

¹⁷ Mikhail Chester and Arpad Horvath, *High-speed rail with emerging automobiles and aircraft can reduce environmental impacts in California's future*, Environmental Research Letters, July 2012, p. 5 [Interpolated from the chart data in Figure 1]

¹⁸ Chester and Horvath, 2012, p. 4.

¹⁹ pp. 13-15.

²⁰ Chester and Horvath, 2012, p. 9.

²¹ p. 19.

²² p. 13.

²³ p. 15.

²⁴ p. 20.

²⁵ p. 1.

²⁶ p. 5.

Attachment 2

High-speed rail with emerging automobiles and aircraft can reduce environmental impacts in California's future

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Received 16 March 2012

Accepted for publication 2 July 2012


Published 26 July 2012

Online at stacks.iop.org/ERL/7/034012

Abstract

Sustainable mobility policy for long-distance transportation services should consider emerging automobiles and aircraft as well as infrastructure and supply chain life-cycle effects in the assessment of new high-speed rail systems. Using the California corridor, future automobiles, high-speed rail and aircraft long-distance travel are evaluated, considering emerging fuel-efficient vehicles, new train designs and the possibility that the region will meet renewable electricity goals. An attributional per passenger-kilometer-traveled life-cycle inventory is first developed including vehicle, infrastructure and energy production components. A consequential life-cycle impact assessment is then established to evaluate existing infrastructure expansion against the construction of a new high-speed rail system. The results show that when using the life-cycle assessment framework, greenhouse gas footprints increase significantly and human health and environmental damage potentials may be dominated by indirect and supply chain components. The environmental payback is most sensitive to the number of automobile trips shifted to high-speed rail, and for greenhouse gases is likely to occur in 20–30 years. A high-speed rail system that is deployed with state-of-the-art trains, electricity that has met renewable goals, and in a configuration that endorses high ridership will provide significant environmental benefits over existing modes. Opportunities exist for reducing the long-distance transportation footprint by incentivizing large automobile trip shifts, meeting clean electricity goals and reducing material production effects.

Keywords: life-cycle assessment, high-speed rail, transportation, greenhouse gas

 Online supplementary data available from stacks.iop.org/ERL/7/034012/mmedia

1. Background

Deployment of new and more fuel-efficient transportation modes is expected in the coming decades. Next generation automobiles and aircraft are already entering the market.

Despite major political and economic roadblocks in the United States, federal, state, and regional transportation and land-use planners are discussing high-speed rail (HSR) as a potentially better investment for future mobility. The discussion of new transportation options is often coupled with the identification of strategies to help reduce congestion and travel times. With increasing populations

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and long-distance transportation demand forecasts, HSR was made a centerpiece of the American Recovery and Reinvestment Act as a modal diversification strategy. While several corridors are under study, California in 2008 authorized \$9.95 billion in bonds for their 1200 km system and the state legislature recently approved funding to start construction. Engineering and planning work are already underway, with possible groundbreaking in 2013 (CAHSRA 2012). While many technical, legal, economic, community and political battles loom, the California HSR (CAHSR) Authority has made significant progress towards deploying the system, which will connect Sacramento, San Francisco, Los Angeles and San Diego. In addition to direct mobility benefits, CAHSR has the potential to reduce long-distance transportation energy consumption and air emissions, provided measures are taken to encourage high ridership, minimize construction effects, and establish clean electricity contracts (Chester and Horvath 2010).

To understand the comprehensive energy and air emissions effects of deployment and adoption of CAHSR, a life-cycle assessment (LCA) framework should be used to assess future modes in the California corridor. The energy and environmental tradeoffs of CAHSR have been examined with then-planned vehicles and fuels (Chester and Horvath 2010) by constructing a life-cycle inventory using information from CAHSRA (2005), the then-current design data and with groundbreaking expected around 2010. However, many new corridor plans and design considerations have been made warranting new outlooks for the system. Forecasts for a future long-distance transportation system should include emerging and expected automobile, aircraft and HSR improvements. In this study, an environmental assessment of future long-distance travel is developed using the California corridor as a case study. We start by developing a per passenger-kilometer-traveled (PKT) attributional assessment of future transportation systems that expands the results of Chester and Horvath (2010) by evaluating (i) emerging automobiles and aircraft, (ii) new train designs, and (iii) low-carbon electricity scenarios. We then develop a consequential assessment for the corridor to determine the net effects of the decision to build a new HSR system. Following our past work, we identify the critical system design parameters that lead to transportation systems having larger or smaller human and environmental footprints than their competitors. Our goal is to identify the potential design, construction and operation pitfalls early so that transportation planners and operators can reduce future impacts at potentially lower cost.

The goal of this research is to develop a framework for assessing the environmental effects of long-distance transportation in the California corridor to provide more comprehensive measures of the greenhouse gas, human health and other environmental damage potentials of future systems. We anticipate that this framework will (i) aid policy and decision makers in the assessment of long-distance transportation options, (ii) provide HSR designers, engineers and operators with information on how to best reduce environmental damage potentials, and (iii) provide a standard methodology by which other US and international transportation systems can be evaluated.

2. Methodology

An environmental assessment is developed for automobiles, aircraft and HSR operating in the California corridor between 2030 and 2050. When performing an LCA a year of analysis is generally defined. We choose to evaluate modes in a two-decade range to acknowledge the uncertainty in adoption of HSR and the challenges of estimating future life-cycle process improvements in a single year.

LCA is the preeminent framework for evaluating the energy and environmental effects of complex systems and can be used to understand the tradeoffs of transportation decisions. Life-cycle inventorying (LCI) is one stage of LCA, the quantification of environmental flows. Impact assessment must be performed to connect physical flows to the human health, ecosystem quality, climate change and resource effects of ultimate interest (ISO 2006, Jolliet *et al* 2003). End-use energy and air emissions are first inventoried. Air emissions include greenhouse gases (GHG) and conventional air pollutants (SO_x , CO, NO_x , VOCs, PM_{10} and $\text{PM}_{2.5}$). GHGs are reported as CO_2 equivalence (CO_2eq) using radiative forcing multipliers of 25 for CH_4 and 298 for N_2O for a 100 yr horizon. The US Clean Air Act established a regulatory framework for criteria air pollutants to reduce direct human and environmental impacts. SO_2 , CO, NO_x , PM and ozone are regulated through National Ambient Air Quality Standards. We evaluate NO_x and VOCs because they are ozone precursors.

The LCI results are joined with human and environmental impact characterization factors from the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI, v2.03) in the development of a life-cycle impact assessment (LCIA) (Bare *et al* 2002). Impact characterization factors are used to show the maximum potential effects of pollutant releases. In addition to global warming (CO_2eq), human health respiratory, acidification, tropospheric ozone (smog) and eutrophication impact potentials are determined. We stress that impact potentials are the maximum effects that can occur and actual effects may be lower, or potentials may never turn into damages. However, given the challenge of combining air transport and chemistry modeling with concentration-response functions, endpoint damages have not been determined for this study. Bare *et al* (2002) provide background for TRACI and how air emissions are used to determine impact potentials.

2.1. Efficient and electric automobiles

Improved gasoline efficiency and plug-in hybrid electric vehicles (PHEV) are expected to have significant market penetration by 2030 (EPRI 2011). The 2007 US Energy Independence and Security Act established fleet-wide fuel economy standards at 35 mpg (15 km l^{-1}) by 2020. Furthermore, the US EPA and the National Highway Traffic Safety Administration have proposed a $102 \text{ g km}^{-1} \text{ CO}_2$ standard for 2025, which is equivalent to a fuel economy of 54.5 mpg (23 km l^{-1}) (EPA 2011). Given these policies and trends, it is reasonable to expect future long-distance

automobile travel to occur in a vehicle that has improved fuel economy from the 21 mpg (9.6 km l⁻¹) average today (ORNL 2011). While a fuel economy standard does not translate to actual onroad performance, the range of economies modeled is intended to illustrate future potential performance of improved vehicles. Congestion effects are not modeled and it is acknowledged that this would increase the automobile footprint. Second-generation biofuels are likely to be a widespread transportation fuel in the future (Scown *et al* 2012), but we focus on reformulated-gasoline and electric vehicles.

Vehicle manufacturing, battery manufacturing (including replacement) and operation are evaluated with the GREET 1 (fuel-cycle) and 2.7 (vehicle-cycle) models (ANL 2011). A 35 mpg, 1500 kg sedan and a 55 mpg, 900 kg (before batteries) PHEV (ANL 2011) are modeled to meet future fuel economy standards. Large battery pack plug-in and battery electric vehicles are expected to have market penetration gains in the next decades, and we evaluate a PHEV60 (60 mi, 97 km all electric range) assuming that the first 97 km of a 480 km California long-distance trip are in charge-depleting mode and the vehicle is configured as a parallel hybrid drivetrain. GREET models vehicle emissions with a drive cycle that is 43% city and 57% highway. Using drive cycle characterizations from Karabasoglu and Michalek (2012), vehicle emissions are adjusted assuming that the beginning and ending 24 km of the trip occur in cities with the remainder occurring on highways. We believe that our PHEV60 assessment is conservative as future vehicles may have improved battery energy densities and intelligent operational controls that more effectively utilize a blended mode. The PHEV60 is modeled with one lithium-ion battery replacement and specifications are consistent with those modeled by Michalek *et al* (2011). All automobiles are evaluated with a 260 000 km lifetime. Brake wear, tire wear and evaporative losses are included. General maintenance and tire replacement are evaluated using EIO-LCA (GDI 2011). Lead-acid and lithium-ion battery replacement are evaluated with GREET. The energy and environmental effects associated with insurance industry operation (e.g., electricity consumption, waste management) are captured using EIO-LCA (GDI 2011).

The energy inputs and air emission outputs generated by the construction and maintenance of the California highway (interstate and major arterial) system serve as the infrastructure basis for future long-distance statewide travel. There are currently 12 100 km of California highways facilitating 250 billion annual vehicle-kilometers-traveled (VKT) (FHWA 2009). Across all California roadways there are 380 billion annual VKT and this is forecast to increase to 480 billion VKT by 2040 absent a HSR system (CAHSRA 2012). The 74% of asphalt surfaces are specified with a 15 yr life and concrete surfaces at 25 yr (both surface sub-bases are assumed to last 100 yr). Material production, transport, equipment process, and direct emissions from construction and maintenance activities are modeled with PaLATE (2004). Roadway construction effects are allocated to vehicles based on VKT splits and maintenance to heavy duty vehicles since

damage follows a fourth-power relationship to axle load (Huang 2004). Roadway design specifications, herbicide use and overhead lighting are included (Chester 2008).

Gasoline vehicle and PHEV60 energy production are evaluated with GREET and are specified with parameters commensurate with Michalek *et al* (2011). California reformulated gasoline is used, and GREET estimates that 18% of crude oil feedstock will be extracted from oil sands by 2020. For the PHEV60 and CAHSR, future regional electricity is used (this is detailed in later sections). Gasoline and electricity production include raw fuel feedstock inputs, transportation, processing (or generation) and distribution.

2.2. High-speed rail

HSR effects are determined following the approach of Chester and Horvath (2010) but updated to acknowledge that a future CAHSR system will likely see improved train performance and an opportunity for increased renewable electricity usage. The assessment by Chester and Horvath (2010) was designed to evaluate the high-speed rail system specified by CAHSRA (2005) under a life-cycle lens. CAHSRA (2005) performs an energy assessment based on large 1200 seat trains consuming an exaggerated 170 kWh of electricity per VKT. Despite acknowledging this over-estimate, Chester and Horvath (2010) chose not to redesign the CAHSRA (2005) system or challenge the publicized parameters. Given the uncertainty in the CAHSRA (2005) propulsion electricity estimate, primary data collection exercises were undertaken to develop improved electricity consumption estimates for a future CAHSR train. In this study, we evaluate three train sizes (400, 670 and 1200 seats) and use actual electricity consumption outcomes from Deutsche Bahn, instead of relying on literature. A range of HSR propulsion electricity exists in the literature and a survey and comparison are performed in the supplementary information (SI, available at stacks.iop.org/ERL/7/034012/mmedia). Actual electricity consumption factors for ICE trains (preliminarily chosen by CAHSRA 2005) were gathered from Deutsche Bahn (2011) and correspond to those reported by IFEU (2011) resulting in 13, 20 and 36 kWh/VKT for the respective train sizes. Regenerative braking effects are included. It is possible that the trains deployed in California will be several generations newer and will consume less electricity, but without data on future technologies we choose not to make projections, and instead assume current state-of-the-art technology for CAHSR.

A study has been performed for the CAHSR Authority to evaluate the feasibility of deploying wind and solar electricity to meet system-wide electricity demands (Navigant 2008) and strategies have been developed to power the stations and trains with 100% renewable energy (NREL 2011). While funding for a renewable electricity infrastructure remains uncertain, this future configuration is considered using existing PV and solar study LCIs (Pehnt 2006) with an 80% wind and 20% solar mix.

Vehicle (manufacturing, maintenance and insurance), infrastructure (construction, operation, maintenance and

parking), and non-renewable electricity generation scenarios follow the methodology used in Chester and Horvath (2010, 2011) and are adjusted for future electricity inputs. The infrastructure assessment matches the results of Chang and Kendall (2011) when a commensurate system boundary is used. Whenever possible, we apply the Western Electricity Coordinating Council (WECC) electricity mix generation emission factors to scenario life-cycle components. Without a contract to purchase electricity from a particular supplier, electricity consumption by CAHSR should be evaluated in the WECC reliability network (Marriott and Matthews 2005), capturing flows across nearby states, including imports to California. Vehicle and infrastructure effects from WECC electricity use are based on a mix that has reached 2020 Renewable Portfolio Standards (WECC-RPS) (WECC 2011). Furthermore, a projected 2040 mix that has reduced coal inputs resulting in 60% carbon emissions intensity of today is also included (WECC-2040).

2.3. Next generation aircraft

Midsize aircraft (130–160 seats) were responsible for 79% of domestic US air travel PKT in 2009 (BTS 2011) and current and future planes are evaluated to capture significant improvements in engine fuel use and emissions. A Boeing 737–800 is used to evaluate currently operating state-of-the-art aircraft. The 737–800 seats 160 and uses CFM56-7B26/2 engines. The Bombardier CS300-ER is an emerging aircraft that offers 20% fuel savings (and commensurate GHG savings) and additional emissions reductions over in-service planes. The CS300-ER will use Pratt and Whitney (PW) 1524G PurePower engines offering propulsive efficiency gains while carrying up to 130 passengers. For both aircraft, maintenance and insurance costs are based on 737–800 airframe materials, engine materials, insurance and hourly costs of employee benefits, reported by BTS (2011). To provide perspective on energy and environmental gains in air travel, the 737–800 and CS300-ER are compared against the legacy Boeing 737 series (<800) which has been a workhorse of the mid-haul market (Chester and Horvath 2010).

Fuel and emission indices are used to determine landing–takeoff (LTO) and cruise phase effects for a San Francisco to Los Angeles flight. In previous studies, LTO effects were determined with FAA (2010) and cruise phase with EEA (2006) data. These software and data do not offer the flexibility or transparency to evaluate future engine improvements. FAA (2010) reports fuel and emission indices which are combined with time-in-mode and rated thrust estimates to determine total flight effects for the 737s. The CFM56-7526/2 engines on the 737–800 achieve 25% reductions in CO, 27% in HC, 31% in NO_x, and 97% in smoke emissions relative to CAEP6 engine emission standards (ICAO 2010). ICAO (2010) does not yet report PW1524G engine testing results, however, Hoke (2011) reports 64% reductions in CO, 96% in HC, 58% in NO_x, and 50% in smoke emissions relative to CAEP6 standards, which were used to determine the CS300-ER flight emissions. Flight LTO and cruise fuel consumption and emissions were validated

by PW engineers (Pratt and Whitney 2011). Aircraft energy and environmental effects are determined with fuel and emission indices and rated thrust estimates by flight phase (see the SI for details, available at stacks.iop.org/ERL/7/034012/mmedia). The potential for respiratory, acidification and eutrophication impacts from non-LTO emissions are included (Barrett *et al* 2010, Tarrasón *et al* 2002).

3. Modal attributional footprinting

The assessment and allocation of direct and ancillary processes to each transportation mode reveal the life-cycle activities that should be targeted for the greatest environmental improvements. Consistent with existing transportation LCA studies, results are normalized to a per-PKT functional unit to evaluate the effectiveness of providing passenger mobility. For automobiles and CAHSR, a dearth of data exists to provide a rigorous assessment of expected occupancy rates. For aircraft, detailed reporting provides strong indicators for future utilization (BTS 2011). To avoid universally characterizing modal performance by normalizing to an average occupancy, reasonable and expected high and low occupancies are assessed to capture the *potential* of modes. For all modes, the high occupancy is the number of seats. Low occupancies are designed to consider off-peak ridership. While it is possible for CAHSR and aircraft to operate with a single passenger, this outlying case is not informative and therefore not shown. Low occupancy for CAHSR is approximately one-quarter of seats, and for aircraft is the lower occupancy quartile in 2009, determined from BTS (2011). Figure 1 shows global warming and human health respiratory life-cycle results for each mode for high and low occupancy.

GHG emissions are dominated by vehicle propulsion (energy production for CAHSR and vehicle operation for automobiles and aircraft) but show increases of 38–54% for automobiles, 77–116% for future CAHSR and 13–34% for aircraft when all life-cycle components are included. Results for future long-distance modes are consistent with those identified in past transportation LCA studies (Chester and Horvath 2010, 2009) even when new data and modeling are included (ANL 2011). Automobile vehicle manufacturing is dominated by steel and plastic use (ANL 2011), and maintenance effects are largely the result of supply chain electricity (GDI 2011). CAHSR infrastructure construction effects are dominated by concrete use. Approximately 67% of CAHSR infrastructure emissions are the result of cement production for concrete use and 9% are related to steel production. Automobile infrastructure effects are small compared to past studies because only highways are included to isolate long-distance infrastructure. The inclusion of trip-specific infrastructure provides a clearer comparison of corridor travel by focusing only on roads, tracks and airports needed for each trip. Non-propulsion fuel-cycle effects are primarily the result of refineries, oil and gas extraction activities, and supply chain electricity use (ANL 2011, GDI 2011). With distributed hard infrastructure and its long-distance nature, the life-cycle effects of air

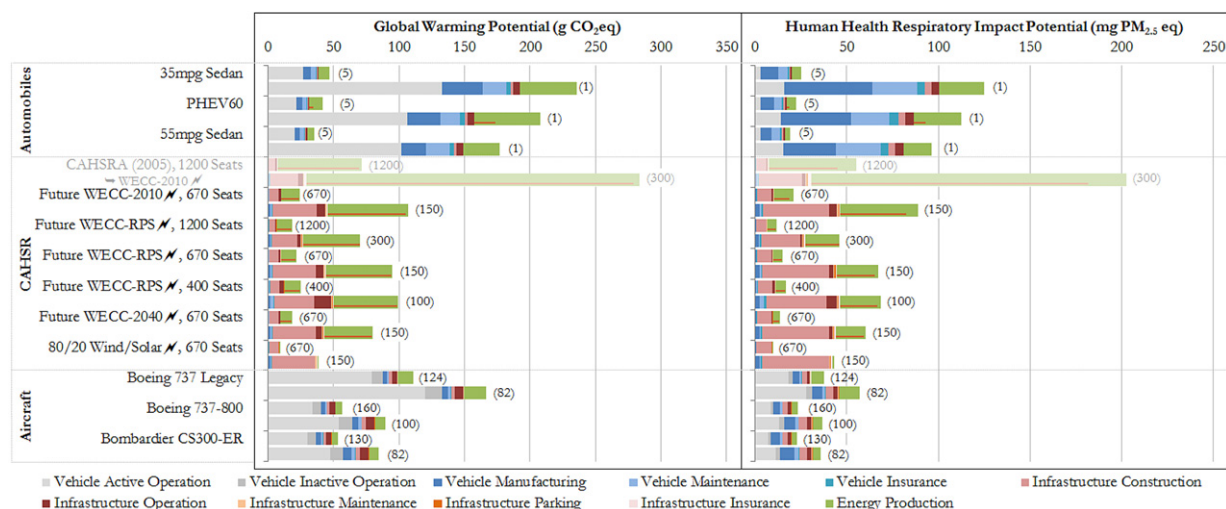


Figure 1. Global warming and human health respiratory impact potential results per PKT. For each mode, results at long-run average high and low occupancy (shown in parenthesis) are displayed as juxtaposing bars. Previous research by the authors reported electricity generation effects for electric vehicle propulsion in the *Vehicle Operation* life-cycle groupings. In an effort to improve the spatial characterization of effects, electricity generation for CAHSR propulsion is reported in *Energy Production* and differentiated from upstream effects (e.g., emissions from fuel extraction and transport) by a red line. The CAHSRA (2005) train is shaded gray to emphasize that it is an unlikely outcome, but reported for comparative purposes.

travel are diminished when results are normalized per PKT. WECC-2040 electricity reduces HSR GHG propulsion emissions by 26% but infrastructure construction effects continue to add heavy burdens to life-cycle results showing the need for low- CO_2 materials.

Across modes and life-cycle groupings, PM_{10} emissions are often generated by mining activities for raw materials, and $\text{PM}_{2.5}$ emissions by supply chain combustion processes including electricity generation, the latter contributing to human health respiratory impact potentials. While PHEV60s produce fewer $\text{PM}_{2.5}$ emissions during propulsion, battery manufacturing and associated electricity requirements have the potential to contribute significant $\text{PM}_{2.5}$ and SO_x emissions and increase respiratory impacts beyond the 35 mpg sedan. This implies that strategies should be developed that minimize human and environmental exposure as the battery industry expands, and that meeting or exceeding RPS standards will reduce impacts across automobiles and CAHSR. For CAHSR, concrete and steel production including upstream mining activities are larger than propulsion effects. The dominating share of environmental impact potentials are often in non-propulsion components and are shown in figure 2.

Several common processes dominate the environmental impact potentials. Vehicle manufacturing and maintenance are affected by assembly activities, but are dominated by the use of metals (i.e., steel, aluminum and copper) and its associated electricity demands for processing. Supply chain truck transport for these processes also contributes heavily to CO , NO_x and VOC emissions. Asphalt and concrete use dominate infrastructure construction and the use of these materials is affected primarily by direct emissions at hot-mix asphalt and cement kilns, and their associated electricity demands. Airport ground support equipment use contributes heavily to aircraft life-cycle results. For automobiles and

aircraft, fuel production effects are largely the result of refinery electricity demands and extraction activities, and for HSR are dominated by primary fuel extraction, processing and transport. Air pollutant emission reductions may achieve the largest benefit-to-cost ratio by targeting infrastructure and supply chain effects.

Assuming that options exist, the decision by a traveler to take a mode produces marginal effects in the short-run, a subset of those reported in figures 1 and 2. For example, the decision to walk instead of driving immediately avoids fuel consumption and emissions from vehicle operation. Including mid-run life-cycle components avoids vehicle manufacturing, vehicle maintenance, vehicle insurance, infrastructure maintenance, and associated supply chain effects including fuel refining. Ultimately, a critical mass of travelers choosing to walk instead of drive would have long-run effects including reductions in roadway capacity needs avoiding future infrastructure construction. Marginal effects are critical for understanding the change in energy or environmental outcomes from a policy or decision. Long-run average effects are reported to provide a comprehensive set of indicators for analysts, however, future analyses with these results should consider marginal effects at specified timescales. Long-, mid- and short-run average and marginal comparisons are presented in the SI (available at stacks.iop.org/ERL/7/034012/mmedia).

Considering the potential of a mode to environmentally outperform another is critical to developing strategies that acknowledge different long-term operating characteristics. Modal potential considers the occupancy range in which transportation systems operate instead of averages which can mask peak and off-peak, position along lines and day-of-week characteristics, to name a few. Future CAHSR ridership forecasts have been developed and scrutinized (Brownstone *et al* 2010). Designs that do not access airports

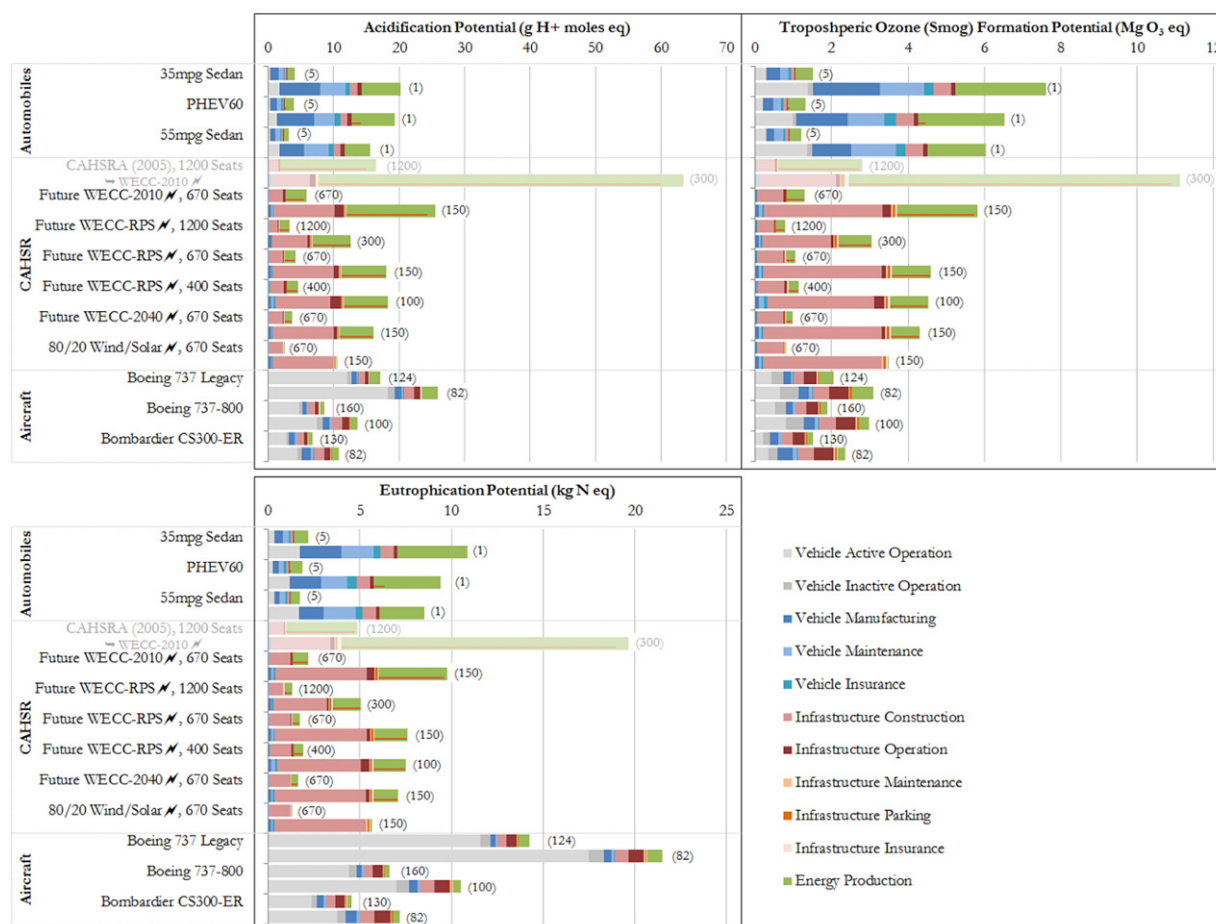


Figure 2. Environmental impact potentials per PKT.

and city centers, hub existing transit at HSR stations and encourage urban infill are inimical to high ridership, and risk disincentivizing trip takers switching from autos. Technical, political, community and economic roadblocks exist for many high ridership configuration options that could ultimately lead to lower than optimal adoption outcomes. Furthermore, even with high ridership configurations, the system will at times (whether during off-peak or end-of-lines) exhibit fluctuations and these instances should be considered in policies that target marginal operation. Given the large uncertainty in a future HSR system's ridership, figure 3 shows the CAHSR life-cycle and vehicle propulsion effects at varying occupancy levels against a current mean occupancy automobile and midsize aircraft (represented as a 2.2 passenger 35 mpg sedan and 116 passenger 737–800).

The sensitivity to vehicle occupancy is used to illustrate breakeven points, or the ridership levels where one mode is equivalent to another in the long-run. Occupancy levels of between 80 and 280 passengers produce HSR GHG-equivalency to future automobiles or aircraft (depending on train size). However, for acidification potential, this equivalency increases to between 160 and 420 passengers, or roughly 35–40% average occupancy for trains. This assumes that the WECC has met the RPS. The acidification breakeven points capture the dynamic of mode switching from low-sulfur liquid fuels to high-sulfur electricity and

reaffirm the findings of Chester and Horvath (2010) that deployment of HSR should occur with mandates for cleaner propulsion electricity sources to avoid increased human and environmental impact potentials. The breakeven point assessment highlights the importance of future ridership scenario considerations in the determination of potential corridor effects.

4. Regional consequential effects

To evaluate the net effects of the decision to implement a new system in the corridor, a consequential assessment is developed. A consequential assessment should compare a *without HSR* future where additional automobile and aircraft capacities are needed to meet growing demands to a *with HSR* future where the new rail system reduces the need to fully build this capacity. Estimates of this capacity expansion have been produced by the Authority (PB 2011) and the LCA methods can be used to evaluate the change in effects in the corridor. The per-PKT results reported in figures 1 and 2 are valuable for understanding the footprint of each transportation system in the long-run but do not allow for direct assessment of the changes in corridor impacts when a new system is implemented. For example, an infrastructure will be constructed to facilitate an

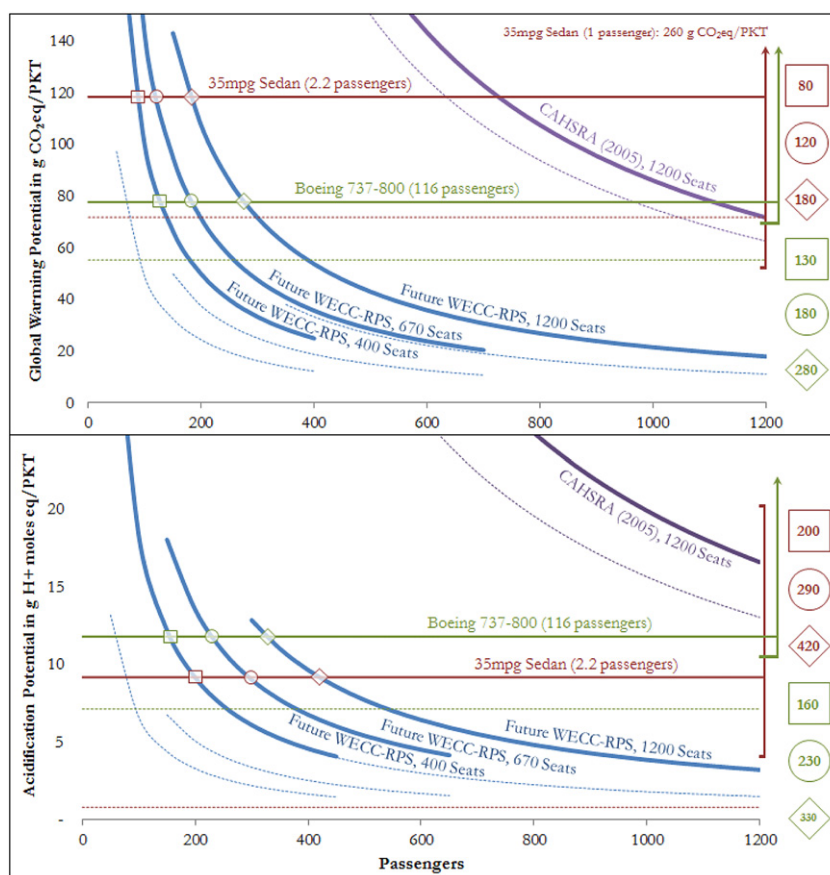


Figure 3. CAHSR global warming and acidification potential sensitivity to vehicle occupancy. Life-cycle results are shown as solid colored lines and vehicle propulsion as dotted. Breakeven points are shown as red and green shapes on the figure and corresponding ridership levels are shown on the right side. While average occupancies are shown for the 35 mpg sedan and 737–800, their potential ranges are shown as vertical lines on the right side.

expected level of service for CAHSR. This infrastructure may be flexible to accommodate more passengers if demand is greater than anticipated. Yet if the per-PKT GHG results in figure 1 are applied to the different PKT demand forecasts, different net infrastructure construction effects would be falsely determined (i.e., the infrastructure construction effects remain the same with different ridership outcomes). While the attributional assessment can inform questions like: *what are the major energy and environmental processes in the life-cycle of a transportation system, and how can they most effectively be reduced?* A consequential assessment is needed to answer questions such as: *how can California deploy a future multi-modal transportation system with the lowest human and environment impacts?*

The energy and environmental costs of a new HSR system should be compared against the avoided costs of automobile and air infrastructure expansion, assuming there is long-distance travel demand growth. PB (2011) estimated that 3600 freeway lane km and 13 000 m of runways, and 115 additional airport gates are needed to meet growing corridor demand in the coming decades. This is the only assessment of future infrastructure expansion needs to date and it is possible that this is an aggressive estimate. PB (2011) estimates are based on full corridor future capacity (117 million auto and air trips) and the most recent forecasts estimate 33 million HSR trips at high ridership. Therefore, 28% of infrastructure

expansion effects are considered (i.e., 1000 lane km, 3600 m of runways and 32 additional airport gates) to account for only the avoided effects of HSR travelers and may be an aggressive allocation because of induced demand. Using roadway design guidelines (AASHTO 2001), construction and maintenance energy and emissions were calculated with PaLATE (2004) following Chester and Horvath (2009). The runway expansion would come with an estimated 670 000 m² of taxiways and tarmacs. Construction and maintenance of concrete runways and asphalt taxiways and tarmacs are also evaluated with PaLATE (2004) using dimensions reported by Chester (2008). For all surfaces, it is assumed that the wearing courses will last 20 yr and subbases 50 yr. It is also assumed that infrastructure expansion will start 10 yr after it has been decided not to build HSR, and will occur over 30 yr. Airport gate and corresponding concourse expansion construction follow the methodology of Chester (2008). Detailed construction and maintenance schedules for the infrastructure expansion are provided in the SI (available at stacks.iop.org/ERL/7/034012/mmedia).

Consequential effects are highly sensitive to modal shifts and forecasting of HSR energy and environmental effects should occur with uncertainty assessment. Forecasts for CAHSR adoption have only been reported by the Authority making rigorous uncertainty assessment challenging. Adoption discussions by the Authority have been presented through

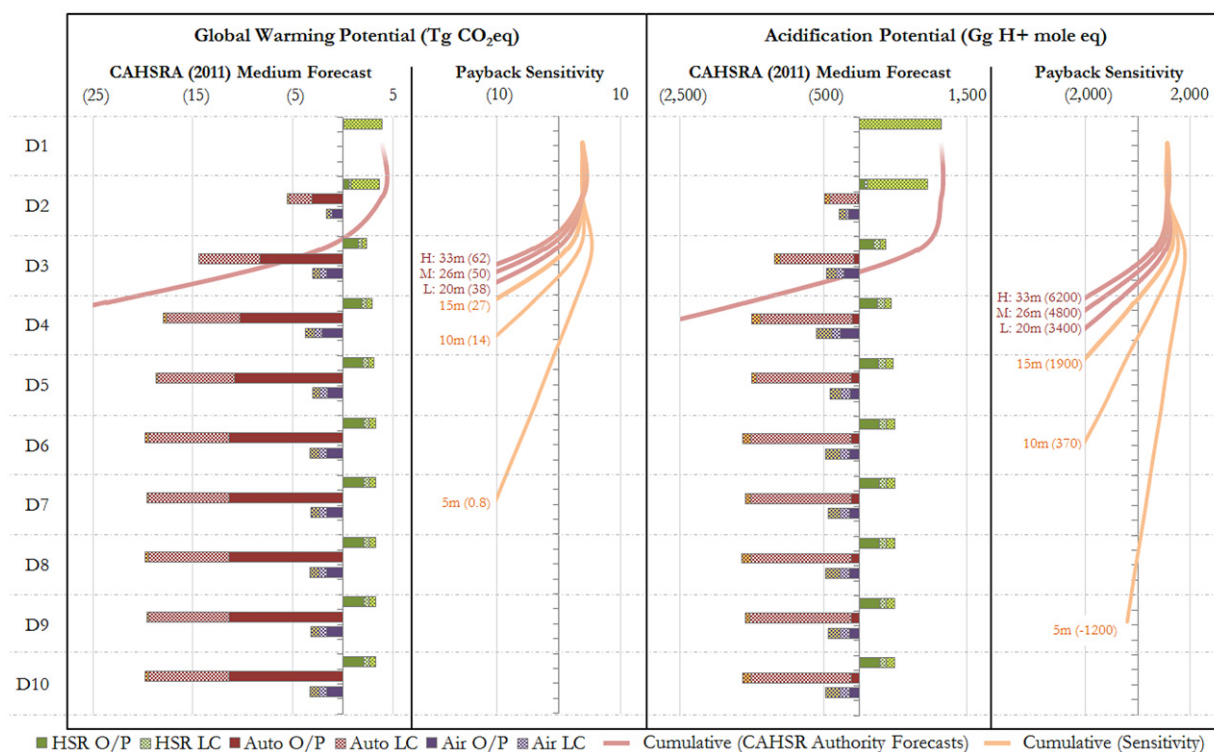


Figure 4. Decadal (D) consequential global warming and acidification potentials including payback for phase 1. O/P = operation and propulsion components (impacts from energy consumed to move vehicles). LC = life-cycle (excludes operation and propulsion components). Life-cycle effects are separated by infrastructure expansion (yellow background) and non-infrastructure (e.g., vehicle manufacturing and maintenance). After each ridership forecast (shown in millions (m) of annual trips in 2040), the 50 yr savings are shown in parentheses. These savings are the GHG or acidification benefit (negatives are costs) after 50 yr from groundbreaking.

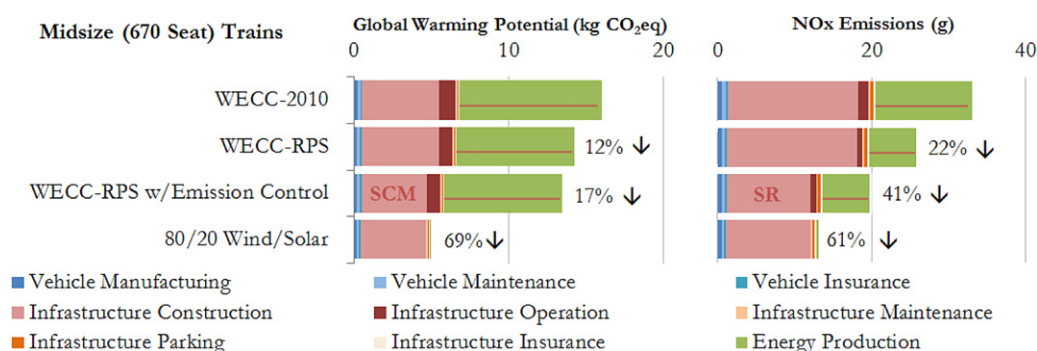


Figure 5. Energy and emission control strategies for reducing environmental impacts per VKT.

without HSR and with HSR forecasts. The consequential assessment considers the difference between these two, essentially, what environmental changes have occurred in California as a result of implementing HSR. The current forecasts report that by 2040 CAHSR Phase 1 (San Francisco to Los Angeles) will perform between 27 and 41 million annual VKT (PB 2012a). The Authority's medium with HSR forecast (34 million HSR VKT) displaces 5.8 billion auto VKT and 5.1 million air trips annually, generating between 20 and 33 million trips on the new mode (PB 2012a, 2012b). Using these forecasts, the Authority's medium (middle) projection is first evaluated to determine the consequential effects at full adoption in 2040. The WECC-RPS 670 seat HSR train is compared against displaced travel in a 35 mpg sedan and

737–800 aircraft (assumed to be reasonable representative vehicles for 2040). In the without HSR scenario, it is estimated that auto travel will increase from 380 billion VKT today to 480 billion VKT, and air travel will increase to 33 million trips (PB 2012b).

The deployment of CAHSR will create induced demand as a subset of trip takers who would not travel by auto or air now find the generalized cost for the journey lower than existing options (Outwater *et al* 2010). Additionally, access to and from HSR stations by autos and other modes may induce new system-wide demand. The CAHSRA (2012) with HSR forecast includes estimates of new trips and these are bundled in the aforementioned VKT. We model induced demand implicitly through the change in travel reported by CAHSRA (2012). A summary of the with HSR and without

HSR consequential analysis critical parameters is provided in the SI (available at stacks.iop.org/ERL/7/034012/mmedia).

The consequential assessment evaluates the difference between a future where CAHSR has or has not been constructed. Figure 4 shows the GHG and acidification potential for operation/propulsion and other life-cycle (including the avoided expansion of auto and air infrastructure) effects aggregated per decade for Phase 1 of the system (San Francisco to Los Angeles). The cumulative effect curve shows the time until payback. Given the uncertainty in the forecasts (Brownstone *et al* 2010), a payback sensitivity analysis is performed on the high adoption scenario as reported by the Authority (41 million VKT). The sensitivity analysis evaluates how long it takes CAHSR to achieve payback given certain adoption levels (for perspective, the Authority's low adoption scenario is 66% of ridership in the high adoption scenario) and considers the high (H), medium (M) and low (L) scenarios followed by decreases of 5 million (m) annual riders.

The payback sensitivity reveals several important considerations for transportation planners and air quality policy makers. The cumulative plum-colored lines for the high, medium and low forecast figures show that the GHG payback will likely occur between 20 and 30 yr (D3) after groundbreaking and acidification potential after 20–40 yr. However, payback is highly sensitive to reduced automobile travel. The 5.8 billion auto VKT displaced dominates emissions changes in the corridor and the effects from reduced air travel and CAHSR are small. The reduced auto impacts are significantly affected or dominated by life-cycle components, in particular, avoided vehicle manufacturing, vehicle maintenance and gasoline production. For GHGs the sooner the system is implemented the more opportunity it will have to help meet GHG reduction policies aiming for 80% of 1990 statewide emissions by 2050. Larger trains or more carbon-intensive electricity generation will delay the payback further. Acidification, the release of SO_x and NO_x emissions which are of concern for respiratory and cardiovascular (through secondary particle formation) effects, agricultural impacts and increased built environment maintenance costs, are dominated by life-cycle processes. For infrastructure life-cycle processes acidification is dominated by the combustion of sulfur-bearing compounds in clinker manufacturing for cement used in concrete freeways, and for non-infrastructure life-cycle processes supply chain electricity use. Ultimately, impacts should account for the time-based radiative forcing of GHGs, high-altitude CO₂ emissions effects, and the shifting of human and environmental effects from vehicle tailpipes to powerplants, to name a few additional factors. We reserve these analyses for future studies. The results of the consequential assessment are highly sensitive to automobile trips avoided and efforts should be made to validate the travel demand model used by the Authority.

5. Strategies for reducing environmental impacts

Given the dominating HSR life-cycle effects from electricity generation and infrastructure construction, strategies can

be identified to reduce the system's footprint, prior to its construction and use. First, by meeting the RPS, GHG and NO_x emissions will be reduced by 12% and 22%. Next, emission control strategies are identified for reducing the infrastructure footprint. For GHGs, the use of supplementary cementitious materials (SCMs) such as fly ash or ground granulated blast furnace slag can reduce concrete's footprint by 14–22% depending on the mixture (Flower and Sanjayan 2007). It is expected that the portion of the infrastructure that impacts roadways will be required to use fly ash to meet California Department of Transportation requirements. Furthermore, if the Authority requires concrete producers to utilize cement kilns with selective catalytic and non-catalytic reduction (SR) advanced NO_x controls, material production emissions can be decreased between 35 and 95%, reducing the potential for acidification, respiratory, smog and eutrophication potential impacts (EPA 2007). Lastly, the use of 100% renewables lowers electricity generation impacts (to only power generation facility construction effects) and combined with the infrastructure control strategies produces the greatest reductions. The effects of these strategies are shown in figure 5.

The impact reduction strategies can decrease GHGs between 12 and 69% and NO_x emissions between 22 and 61%. The costs of implementing these strategies should be compared against other opportunities, particularly those identified by GHG and air quality policies. The 80/20 Wind/Solar train, outside of the infrastructure material footprint, has a payback within the first few years of operation and is equivalent to the GHG assessment developed by the Authority, based on NREL (2011), following California Environmental Quality Act requirements.

The transportation emissions reduction from CAHSR, if operating within a cap-and-trade system, should be evaluated. Cap-and-trade programs have been successfully implemented in the US for NO_x and SO_x, and California continues to discuss a GHG initiative. Cap-and-trade programs remove the potential of any single initiative to reduce aggregate emissions as offsets will be met by increases elsewhere in the economy (Millard-Ball 2009). This is because the cap is designed to equalize the marginal abatement cost and does not encourage each economic sector to undertake reductions. Furthermore, if road and rail emissions are part of the cap but aircraft emissions are not, then the only major GHG change resulting from HSR implementation will be the displaced airplane operational emissions. To meet GHG reduction goals, policy makers should consider where CAHSR potential reductions will be counted, whether that is in a cap-and-trade program or direct transportation mandates.

6. Planning for a sustainable mobility future

HSR has the *potential* to reduce passenger transportation impacts to people and the environment, but must be deployed with process and material environmental reduction measures and in a configuration that will ensure high adoption. We have highlighted the life-cycle hotspots that dominate modal success: (i) train size (affecting electricity consumption,

frequency of service and ridership); (ii) infrastructure construction; and (iii) the fossil fuel intensity of the electricity mix. By identifying low and high adoption outcomes, the potential benefits can be discussed, instead of speculating on a normative long-distance transportation future, especially in light of large uncertainty that surrounds many critical factors of the system. Ultimately, this research aims to inform planners and decision makers about providing sustainable mobility options. Planners and policy makers should be asking how a future sustainable transportation infrastructure can be deployed to meet increasing travel demands with the lowest total cost, including externalities. The environmental benefits of HSR should be joined with other considerations when making decisions about the system. Ultimately, decision assessment should include changes in travel time, productivity, congestion, safety, transportation infrastructure resilience, freight synergies, urban development opportunities and employment, in addition to GHG, human health and environmental damages.

Acknowledgments

The authors would like to thank several organizations and individuals for their intellectual support of this research. Elizabeth Mitchell and Domingo Sepulveda of Pratt and Whitney, and Professor Alan Epstein of MIT and Pratt and Whitney were instrumental in helping us determine future aircraft fuel consumption and emissions. Constantin Vogt of Deutsche Bahn provided valuable information and data on the operations of an established HSR system. Jeremy Michalek, Orkun Karabasoglu (Carnegie Mellon University) and Constantine Samaras (RAND) provided invaluable guidance for the PHEV assessment. Finally, the authors would like to express profound gratitude to Lee Schipper, who passed away during the development of this study, and provided continuous support and encouragement.

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