Evaluating the Creation of a Parallel Non-Oil Transportation System in an Oil Constrained Future

A. Drake, A. M. Bassi and E. L. Tennyson, H. R. Herren

Abstract

The upcoming challenges in the energy sector coupled with growing concern about climate risks are likely to result in dramatic changes in public policy. The choice of energy and transportation strategies will have a profound impact on the future of the United States of America and the world. A business as usual scenario indicates lower GDP, labor-intensive employment with high unemployment and increasing CO_2 emissions. Practical options exist to turn this scenario into higher GDP, good employment and lower CO_2 emissions.

Several policy scenarios were modeled with constrained oil supply using Millennium Institute's T21-USA model. The most positive result by every significant metric (GDP, greenhouse gas emissions, oil used) came from the combination of the two most environmentally positive policies: a massive push for electrified rail transportation (inter-city railroads and Urban Rail) coupled with a massive push for renewable energy, to be completed by 2030.

With an estimated total investment of $250-500 billion in inter-city railroad lines Non-Oil Transportation could supplant most inter-city truck freight and unspecified modal share of passenger service. Up to $60 billion/year ($1.2 trillion over 20 years), spent cost effectively on Urban Rail, should allow for 28% annual growth (not compounded) in urban passenger-miles on Non-Oil Transportation.

These two investments create a 11% larger GDP, only 4% increase in Greenhouse Gas Emissions and a 26% reduction in oil consumption already in 2030 versus a strictly market based reaction. Adding renewable energy improved the results to GDP +13%, GHG -38% and oil consumption -22%.

Introduction

There has been a long-standing perception among both the general public and policy makers that the goals of economic growth, environmental protection, national security and reduced oil use involve a complex set of trade-offs, one goal against another goal[i] [ii](Brown and Huntington, 2008; Howarth and Monahan, 1996). National defense goals are tightly coupled with creating direct oil substitutes for liquid fuels[iii] (CNA, 2007). For example, ethanol is perceived to reduce oil use, but at the cost of heavy subsidies, high levels of natural gas consumption, diversion from food supplies and plowing land set aside for conservation. Coal to Liquids may also require economic subsidies, production comes at significant environmental cost with low energy returned for energy invested, although it reduces imported oil use by direct substitution with synthetic diesel fuel[iv] (Vallentin, 2008).

The results of this study suggest that a virtuous synergy arises from the expansion of electrified rail systems while shifting the national electrical generation towards renewables. Very encouraging long-term economic, environmental and energy results are projected. Rarely can different stakeholders and interests unite behind a common policy that is optimum for each of their disparate priorities. The policies analyzed here are a tentative example of "all things for all people". In fact, expanding electrified rail generates employment while reducing oil consumption[v] (Acharya et al., 2006). The increasing needs for electricity (1% of 2007 demand for new Urban Rail by 2030, and 2% for electrified railroads can be satisfied by modest additional conservation over the next two decades and/or investment in power generation capacity from renewable energy[vi] (DOE, 2008).

Other oil mitigation proposals advocate expanding fossil fuel supply[vii] (Noriega, 2006) or using oil more efficiently. This proposal focuses on creating a parallel Non-Oil Transportation system with a high elasticity of transportation supply. A widespread multi-layer Non-Oil Transportation system can be created in parallel to the existing Oil Transportation system instead of creating oil substitute liquids for the existing oil uses. Non-Oil Transportation both conserves (using less energy much more efficiently) and substitutes fuel (using grid electricity). National security goals are also better met by such a paradigm shift.

The Threshold 21-USA model developed by the Millennium Institute[viii] [ix](Bassi, 2008; Bassi, 2007) and further expanded by the authors, has been employed to carry out the long-term analysis of the expansion of electrified rail as well as other policies.

Energy Issues

The status quo in oil and energy are rapidly being disrupted by a variety of forces, and this disruption will likely lead to significant policy changes[x] [xi](Stern, 2007; IEA, 2006). This paper investigates public policy alternatives and examines the macro economic, environmental, energy, and national defense implications of intense development of a transportation sub sector, electrified rail, with very mature technology and extensive worldwide experience.

According to IEA[xii] (IEA, 2006) and UNDP[xiii] (UNDP, 2004), the main energy-related problems for today's society are the lack of adequate and secure supplies of energy at affordable prices, and the environmental problems caused by ever increasing energy consumption. The World Energy Outlook 2006 highlights three important energy-related challenges:

- Most importantly, the reduction of fossil fuel energy demand;
- The importance of increasing geographic and fuel-supply diversity as confirmed by recent geopolitical events and by high and sustained energy prices;
- The mitigation of climate-destabilizing emissions is more urgent than ever, given that global warming is becoming a real and actual danger.

These challenges and concerns stem from the fact that the IEA and others forecast global primary energy demand increasing by more than 50% by 2030, which will poise extremely difficult challenges to supply and critical issues if not supplied. "Constrained oil supply", regardless of the cause, will profoundly affect economic, environmental, energy and national security realities[xiv] (CNA, 2007).

National Security Implications

Military uses of energy would benefit from less competition for oil from critical needs in the national economy in oil-constrained scenarios, as use of Non-Oil Transportation would be maximized. This was the national strategy during World War II. Lieut. E. L. Tennyson, Office of Chief of Transportation, U.S. Army states that 90% of the 48 state ton-miles were by rail during World War II and trucks were used only when there was no rail alternative. Coal fired steam locomotives substituted for oil-based transportation during World War II. Electricity could substitute for oil in a future acute or chronic oil emergency.

Negative consequences to the Homeland of severely constrained oil supplies can be minimized by shifting to a widely developed, parallel Non-Oil Transportation system. Switzerland and Sweden during World War II are practical examples of functional Western industrial democracies operating with trivial amounts of oil (as little as 1/400th of current US per capita consumption)[xv] (Marland et al., 2003) while enduring a six-year 100% oil embargo.

A broadly functional Non-Oil Transportation system would directly address what may be the greatest security threat to the survival of the United States of America. Russia and Germany were defeated in World War I by a collapse of the home front. The United States would face a similar risk if deprived of large amounts of imported oil for two or more years. Economic collapse coupled with erratic food distribution would place severe stress on all institutions and national will. Revolutions in the Persian Gulf or blockades of the Straits of Hormuz are conventional and credible risks.

Economic forces and the evolution of petroleum exports are potentially greater risks than military action. Flat to modestly declining oil production coupled with rising internal demand by oil exporters would result in a steady reduction of world oil exports, as was seen in 2007[xvi] (King et al., 2008). If the USA fails to get a pro rata share of declining oil exports, a severe and prolonged oil shortage would result. In this respect, the Strategic Petroleum Reserve was designed for short and medium term acute oil shortages, but has little value for chronic, long term oil supply shortfalls.
Well built electrified rail will have growing value in an oil constrained future and should last a half century before major maintenance. In every potential oil supply emergency, acute or chronic, the existence of a Non-Oil Transportation system with elasticity of transportation supply would be a critical strategic asset.

In order to fully represent the onrushing energy and national security challenges mentioned above, the authors have decided to employ Millennium Institute's Threshold 21 (T21) model, customized to the USA[xvii] [xviii](Bassi, 2008; Bassi, 2007) and expand it to simulate transportation strategies under oil-constrained scenarios. T21 is a flexible and intuitive simulation model that uses differential equations as a mathematical foundation and is characterized by feedback, non-linearity, and time delays[xix] (Millennium Institute, 2005).

Characterization of the Approach and Scenarios

Contextualizing a Parallel Non-Oil Transportation System

Non-Oil Transportation System, as used in this paper, does not include all forms of transportation that do not use oil, but only those with: a positive and high elasticity of transportation supply, high energy and economic efficiency, long replacement cycles (i.e. long lived infrastructure and capital equipment), and mature technology. The major modes that meet these criteria are electrified inter-city railroads, Urban Rail, bicycling (including electric assist) and walking. Secondary elements are electric trolley buses and Segways. Electric Vehicles met none of the criteria.

Positive Elasticity of Transportation Supply indicates that large marginal volumes of transportation supply can be added to the system at less than the average cost and within a short to medium term time frame. More rolling stock can be added to rail, rail capacity can be increased with marginal improvements, streets have almost unlimited bicycle capacity and very few sidewalks are at capacity. This increased supply at low marginal cost and lower average cost will have positive economic benefits as their modal share increases.

The authors also use the terms *Constrained Oil Supply* and *Maximum Commercial Urgency*. The former indicates a reduction in per capita oil supply with limited price elasticity of supply for oil. The latter should be interpreted as the maximum effort commercial firms will exert in pursuit of profits, currently exemplified by development of Alberta oil sands. This level of effort is a step below war time efforts, when national survival is clearly at stake.

Overview of the Baseline Scenario

All scenarios simulated with T21-USA assumed a common oil constraint, based on the input of the Association for the Study of Peak Oil & Gas (ASPO), US chapter. ASPO-USA believes that the

United States Geological Survey (USGS) low and medium estimations of the URR (Ultimate Recoverable Reserves)[xx] (USGS, 2000) for conventional oil and natural gas liquids are reasonably on target, considering that two of the biggest exponents of ASPO, Jean Laherrère and Colin Campbell, have estimated the URR to 1.9 trillion barrels for crude oil only[xxi] (Campbell and Laherrère, 1998). For simplicity we analyze the USGS Low scenario (2.2 trillion barrels) [xxii] (USGS, 2000). Prudence suggests that policy makers should make similar conservative assumptions about future oil supplies.

The reference case is a market based approach, with prices as the primary driver of adaptation to shrinking oil supplies and no major changes in energy policy. It is based on a market economy, where (1) Federal laws do not regulate electricity production from renewable energy sources, (2) there is no restriction on CO_2 emissions, and (3) heavy subsidies for ethanol are allocated as proposed by the United States Department of Agriculture (USDA) until 2016[xxiii] (USDA, 2007). The model showed a peak in oil at $350/barrel in 2011, which causes a 9% reduction in GDP. This dramatic decline in economic activity (a severe recession, borderline depression) reduces the price of oil to below $200/barrel due to demand falling faster than supply. This "cheap oil" results in the GDP rebounding by 2% (of the lost 9%) and prices above $200/barrel

Alternative scenarios were added to the reference scenario. One scenario was a maximum push for electrified rail, another was a major push for renewable energy and a third was the two combined. The renewable energy scenario simulates large support for renewable energy, primarily electricity, by the Federal and State Governments. It assumed a Renewable Portfolio Standard (RPS) of 40% by 2025, increasing to 85% by 2035, is approved by the Government (as proposed by the American Council on Renewable Energy -ACORE), that there are still no restrictions on CO_2 emissions, and that subsidies for ethanol production are retained. The results of the two combined efforts appear to be more than simply additive, they is apparently a positive synergy between the two environmentally positive policies.

Description of the Electrified Rail Scenario

The existing transportation system of the United States is almost entirely oil based, at different levels of efficiency[xxiv] (Energy Security Leadership Council, 2006). National modal shares of electrified rail, bicycling and walking are minimal to trivial[xxv] (Plaut, 2005).

Conceptually, this scenario proposes the creation of a comprehensive Non-Oil Transportation system with high energy efficiency and a high elasticity of transportation supply when the Oil Based Transportation system is under stress. Passengers and freight could progressively transfer from the Oil Based transportation system to a parallel Non-Oil Transportation system as oil becomes progressively constrained.

France could be used as a model of Non-Oil Transportation development with the on-going and recently accelerated build-out of TGV high speed passenger rail, trams in almost all towns of 100,000 or more population, electrified railroad lines with a goal of 100% electrification by 2025, widespread rent-a-bicycle programs such as "Vélib'"[1] and support for walkable neighborhoods serviced by Urban Rail. Sweden, Germany, Switzerland, Denmark and others have strong elements of viable Non-Oil Transportation systems[xxvi] [xxvii] [xxviii] [xxix] (Anderson, 2007; Poirier, 2007; Erlanger, 2008; Bottoms, 2003). Following this example, existing North American freight railroads would be electrified and capacity increased. Urban Rail would be built out at a fast rate with associated walkable Transit Orientated Development, busy bus routes that were not converted to rail would be converted to Electric Trolley Buses and transportation bicycling would be encouraged. Unfortunately, electric trolley buses and increased bicycling were not modeled due to data constraints. Expanded evaluation of additional Non-Oil Transportation is deserving of further study.

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[1] For a definition see "Vélib'" at http://www.velib.paris.fr/

Inter-City Railroads

Today, the only significant electrified inter-city railroads in the United States are Amtrak's NorthEast Corridor (Boston to Washington DC), Philadelphia-Harrisburg, Pennsylvania and several commuter rail lines. A series of studies for North American railroad electrification were made in the 1970s[xxx] (Middleton, 2008) but none were implemented due the rapid decline of oil prices. By contrast, Russia finished electrifying the Trans-Siberian Railroad in 2002 and electrified the rail line to the Arctic port of Murmansk in 2005[xxxi] (Gurlev, 1989). France announced in 2006 the goal of "electrifying every meter of French Railroads" and "burning not one drop of oil". Many other nations from Japan to Switzerland operate almost completely electrified railroads and other nations as diverse as Chile, India, Kazakhstan and South Africa operate significant sections of electrified rail.

Electrification has several advantages besides switching from diesel fuel to electricity. Common industrial knowledge suggests that rail capacity increases by 15% because trains can accelerate and brake faster. Electric locomotives last longer with much less maintenance, no refueling issues and are generally higher horsepower[xxxii] (Stodolsky and Gaines, 2003).

Both diesel-electric locomotives and electric locomotives use an electric motor for the final drive. The difference is that an electric locomotive relies upon grid power with generation from diverse sources and the diesel-electric locomotive uses a several MW diesel engine of moderate thermo-dynamic efficiency. An electric locomotive can use regenerative braking and feed power back into the grid, a braking diesel-electric locomotive dissipates its kinetic energy as waste heat. Common industrial knowledge also suggests that that an electric locomotive using 1 BTU of electricity displaces 2.5 BTUs of diesel in flat, rural areas and 3 BTUs of diesel in mountainous and urban areas, the delta being regenerative braking. Transferring heavy truck inter-city freight to double stack container trains with diesel-electric locomotives gives a 9 to 1 reduction in diesel use. Due to a variety of issues including circuitry, the limited use of single stack containers and roll-on trailers, the real world energy savings by transferring inter-city freight from heavy trucks to diesel railroads is likely to be in the 7 or 8 to 1 range. Multiplying 7 or 8 to 1 by 2.5 -3 to 1 gives a rough energy trade of 20 BTUs of diesel for 1 BTU of electricity by transferring inter-city freight from trucks to electrified rail.

Railroad capacity will also have to increase significantly to accommodate a large transfer of freight, and a 15% gain from electrification will be inadequate. Improved controls are one cost effective means of improving capacity, but simply re-installing double and triple tracks torn up after WW II for single track operation will solve the vast majority of capacity issues. A major public-private initiative, CREATE, is underway in Chicago to provide grade separated rail over rail crossings and other bottleneck reductions[xxxiii] (Association of American Railroads, 2002). Similar efforts are needed elsewhere.

Of particular interest is the CSX proposal for their rail line from Washington DC to Miami[xxxiv] (CSX Corporation, 2006) 1,200 miles of grade separation with two regular freight tracks for operation at 60 to 70 mph and a passenger and priority freight track (double track Washington DC to Richmond) for operation at 100 to 110 mph. Applying this model to several main rail lines (perhaps 7,000 to 14,000 miles) would provide more than enough capacity to replace both heavy truck freight capacity and speed and infringe on aviation modal share in those selected corridors.

The Department of Defense has classified 32,421 railroad miles as being "strategic"[xxxv] (Military Traffic Management Command, 1998). This encompasses most main lines (one of two when two main lines are in parallel). Electrifying 34,000 miles of rail lines, even if not exactly the same miles selected by DoD, should transfer the vast majority of rail ton-miles to electrified rail under the Pareto Principle, also known as the "80-20 Rule" The 80-20 rule was assumed for traffic (80% of the freight ton-miles traveled over 20% of the rail mileage).

Electrification of existing inter-city railroads at Maximum Commercial Urgency was set after discussions with John Schumann, P.E. of LTK Engineering Services. North America has seven Class I railroads, four of which are dominant in the United States. The other three Class I railroads plus smaller railroads were combined into a 5th major railroad for purposes of analysis. At Maximum Commercial Urgency, US railroads could electrify at the following rate.

TABLE 1: ASSUMED INTER-CITY RAIL CONSTRUCTION RATES

Year	Miles	Class I Groups	Total Miles
1	0	0	0
2	500	5	2,500
3	1,000	5	5,000
4	1,500	5	7,500
5	2,000	5	10,000
6	2,500	4.5	11,250

At Year 6, the number of high priority lines will diminish and it is anticipated that the rate of electrification will stabilize at the 11,000 miles per year rate. The Pareto Principle (80/20 rule) was assumed for traffic (80% of the freight ton-miles traveled over 20% of the rail mileage).

Cost Estimate for the Expansion of Existing Inter-City Rail

The United States is already a world leader in diesel rail freight modal share and this study models a near total (85%) shift in the existing truck modal share to an enhanced electrified rail mode by 2030 (assuming an oil constrained future). Such a shift will require not just enlarged capacity, but enhanced speed and reliability of rail shipments. Inter-modal freight shipments (local truck delivery combined with long haul rail service) are already expanding rapidly and this model assumes an accelerated rate due to higher oil prices and public and private policies improving and electrifying existing rail ROWs. Lieut. E. L. Tennyson was previously quoted that the USA shifted to 90% rail modal share during World War II. Our model assumes a smaller rail modal share over a much longer time frame, with adequate investment in infrastructure. Barge and pipeline modals shares were held constant.

Trucking currently has the largest modal share in US inter-city freight movements (except for bulk commodities), despite higher costs, due to the speed and reliability of trucks versus current US rail service (Bureau of Transportation Statistics). A major modal shift will require a change in doing business on the part of the railroads. We assume local delivery by truck will continue (although many warehouses will relocate to rail sidings over time) with local or regional inter-modal container transfer.

The high end cost estimate of $500 billion (2008 dollars) would overbuild the US railroad system for capacity (current plus future rail and truck volumes) and would almost eliminate bottlenecks. About 14,000 miles of grade separated three or four track service (comparable to CSX plans from Washington DC to Miami), with one or two tracks devoted to 100 to 110 mph passenger and express freight service would serve most population centers at $20 million/mile. Capacity expansions such as those listed below at $2 million/mile would apply to another 30,000 miles of track (mostly improved signals, grade and curve improvements and converting single track to double track).

TABLE 2: EXAMPLES OF INTER-CITY RAIL CONSTRUCTION COST[xxxvi] [xxxvii] (CSX Corporation, 2006; Machalaba, 2008)

Railroad			Cost	Miles	Cost/mile
BNSF	Trans Con	Los Angeles to Chicago	2 billion	2217	902,120
KCS & CSX	Meridian Speedway	Meridian	300 million	320	937,500
NS	Crescent Corridor	New Orleans to Washington DC	2 billion	1152	1,736,111
UP	Sunset Corridor	Los Angeles to El Paso	2 billion	760	2,631,579
CSX	East Coast Mainline	Washington DC to Miami	25 billion	1200	20,833,333

In addition, electrification of over 60,000 miles of track at $2 to 2.5 million/mile (more for complex installations) and bottleneck reductions such as CREATE brings the total to roughly $500 billion, as mentioned above.

It should be noted that marginal capacity expansion for increased traffic on roads and highways is generally higher than the original cost per unit of traffic, thereby raising average costs as road capacity increases. Conversely, the marginal cost for capacity expansion of rail is lower than the original cost, and increased rail traffic leads to lower average costs. To illustrate, adding a second track shares the ROW and some signal costs with the first track, but it increases track capacity by a factor of three or four. Double tracking reduces rolling stock and labor costs by almost eliminating delays for the tracks to clear. The larger economy benefits significantly from faster and more reliable rail shipments. Improved signals are even more cost effective[xxxviii] (BNSF Railroad, 2008).
Such massive level of improvements would allow rail service quality to equal or surpass truck service in an oil constrained future. Given the cost advantages of electrified rail, this should allow for a projected 83% modal shift of the existing truck traffic to future rail.

Electrified Urban Rail

Urban Rail, in American nomenclature, can be divided into four types. Rapid Rail (such as subways or Metro) that is entirely grade separated and can handle large volumes of passengers. Regional or Commuter rail provides inter-urban or suburban-urban transportation with several miles between stops and often shares tracks with freight trains. Light Rail is like modern EU tram service, with minimal grade separation but mostly private Right-of-Way typically. Streetcars are the smallest Urban Rail, with frequent stops and often with shared lanes with other traffic.

Compared to the U.S., municipalities in Europe were more willing to regulate transit, to provide subsidies to ensure low fares, to mandate the construction of new routes, and to dictate the aesthetics. This led to a wave of public takeovers in the early 20th century and in short order municipal ownership was standard throughout Europe. Private ownership of transit companies continued in U.S., setting the stage for later declines The *coup de grace* was administered by National City Lines (a front company for General Motors, the Firestone Tire Company, Mack Truck, Phillips Petroleum, and Standard Oil of California), which purchased and dismantled transit systems in some 40 cities during the 1930s and 40s[xxxix] (Black, 2006). After World War II, GM threatened to boycott any railroad that electrified. Outside the US, growing transit demand has seen the number of metro systems worldwide go from 17 in the early 1950s, to 55 in the 1980s, to 110 in the 2000s.

After 170 years of experimentation, development, refinement, and widespread operation, urban rail is a mature technology. This allows transit systems to be tailored to virtually any urban situation.

Moreover, changes in demographics, societal attitudes and environmental conditions are increasing the demand for transit-oriented development (TOD). This confluence of trends over the past 10 years may explain why the growth rate of U.S. transit ridership has been greater than the growth rate of vehicle miles traveled on U.S. highways[xl] (Miller and Williams, 2007).

Currently, 0.19% of all US electrical demand goes to transportation[xli] (EIA, 2008). This includes the consumption of Amtrak's NorthEast Corridor, the Long Island Railroad, Metro North and other electrified commuter rail lines, New York city subways, as well as Rapid Rail in Chicago, Boston, Philadelphia, Washington DC, Atlanta, San Francisco's BART, Miami, Los Angeles, and Light Rail and Streetcars in several dozen cities.

The scenario assumed an extremely aggressive increase in electrical demand by Urban Rail of 0.05% of total demand per year. This corresponds to a 28% annual increase in electrical demand, created by new Urban Rail lines, higher density on existing Urban Rail Lines and electrifying current diesel commuter lines. Such a rapid build-out has the historical precedent of an even more intensive build-out. The United States built subways in all of its major cities and electrified streetcar lines in over 500 cities and towns between 1897 and 1916[xlii] (Vuchic, 2007) with roughly 1/3rd the population, 3% to 4% of the GDP (inflation adjusted) and without modern technology.[2] Thirty years of rapid expansion at this rate would result in an almost 8 fold expansion of Urban Rail in the United States. The equivalent of eight new New York subways alone would have a profound impact on urban and suburban mobility in an oil constrained future.

Practical and worthwhile projects exist for such a build-out. This build-out would be greater than all existing plans for Urban Rail lines that could be justified when oil was $30/barrel, but not by an excessive amount. Higher oil prices and changes in development will expand the possibilities of Urban Rail beyond an eight-fold increase. Ed Tennyson prepared a comprehensive analysis of the Washington DC area and concluded that 15 proposed Urban Rail lines were justified at low oil prices (and 3 were not). Darrell Clarke made a comparable review of the Los Angeles Basin with extensive but lower per capita results. These selected Urban Rail projects were justified at $30/barrel oil prices in that the economic benefit to society as a whole clearly exceeded their capital and operating costs by a wide margin.

Cost Estimate for Urban Rail

The primary barriers to more extensive, successful implementation of Urban Rail are in the realms of planning, politics and policy[xliii] (Hughes, 2008). The USA once had, and much of Europe and Japan still have, a dense network of Urban Rail that provided a Non-Oil Transportation alternative to private cars. A variety of public and public-private policies within the USA eliminated much of the competition to oil based transportation[xliv] (Arrington, 2003). In an oil constrained future, rebuilding these lost alternatives appears to be required.

Existing Urban Rail systems can be enhanced for increased ridership at minimal cost (more rolling stock, greater crowding, etc.). However, massive annual gains in ridership (+28% of 2006 base) will require massive new construction. The authors could not specifically identify much more than 350 miles of new Rapid Rail in the USA that would be cost effective, so, like France today, the bulk of the expansion would likely be in Light Rail and streetcars. "Several" billions will be required for such essential projects as connecting the North and South stations in Boston, building the 2nd Avenue subway in New York City and the "Subway to the Sea" in Los Angeles.

Assuming cost effective construction $60 billion (~$30 million/mile) appears to be a reasonable upper limit on annual investment. This translates into about 2,000 miles of Light Rail and streetcars per

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[2] To see list, see http://en.wikipedia.org/wiki/List_of_town_tramway_systems_in_the_United_Statesa

year (Rapid Rail being considerably more expensive and Regional Rail costs being highly variable). Such saturation levels of Urban Rail, continued for decades, appear to be "outside the scope of experience" until one realizes that Mulhouse France (pop 110,900, Metro pop. 273,000) will go from no trams in 2005 to 34 miles in 2011. Extrapolating to similar sized towns in the USA in an oil constrained future, and reflecting on historic streetcars in the USA makes such projections more reasonable in an oil constrained world.

<u>Transit Orientated Development</u>

Transit Orientated Development (TOD) is a largely market driven response to Urban Rail, just as sprawling suburbs and exurbs are market responses to expanded roads and highways[xlv] [xlvi] (Vuchic, 2007; Arrington, 2003). The hallmarks of Transit Orientated Development are walkable neighborhoods and higher density development clustered around an Urban Rail station. Such development uses significantly less energy in housing, public services and private services[xlvii] (Friedman, 2006).

Regional or Commuter Rail has minimal TOD effect but all other forms of Urban Rail typically have a strong impact within a quarter mile of each stop and reduced impacts further out. Streetcars, with their frequent stops, tend to create linear TOD[xlviii] (Vuchic, 2007). Typically, the indirect savings from reduced energy and oil use in providing services exceed the direct savings from substituting high efficiency non-oil transportation with low efficiency car and SUV commuting[xlix] (Friedman, 2006). Washington DC would be an example of this transformation. In 1970, 4% of Washington DC area commuters took the bus to work. Today, over 40% of DC commuters (a slightly different population) take public transit, with the majority using the subway. In 2006, for the first time since WW II, the commuters using public transit exceeded those commuting alone in their cars. Per capita gasoline use in Washington DC has dropped out of the cohort of American cities without Urban Rail and gasoline use is now typical of American Urban Rail cities. In microcosm the construction of a new station (New York Avenue) on an old line (Red) created an immediate office building boom within walking distance[l] (Cervero, 1992).

Even with supportive zoning, TOD rarely starts before an Urban Rail lines opens and we assumed a 3 year delay between new Urban Rail lines and the start of TOD. In an oil-constrained economy, anticipatory TOD may be expected and the scenario results could be understated. This is an area worthy of further research.

Today, there is an unmet demand for Transit Orientated Development (TOD) that predates any oil price rise. Roughly 30% of Americans want to live in walkable or transit oriented development but approximately 2 to 5% of new housing is in this category. The supply falls far short of market demand"[li] (Aurbach, 2008). Public policy inhibits the development of TOD housing (with related commercial activity) primarily by not building the "T" for the "OD" and instead focuses on subsidizing roads, highways and Suburban Sprawl. The market responded to this shift in government policy after WW II (VA mortgage financing for new but not for existing housing, massive road building programs, "forced" integration with associated "white flight") with a massive shift away from traditional downtowns and established neighborhoods to suburban (and later exurban) housing. The roughly twenty year period from 1950 to 1970 saw a wholesale decline and often abandonment of traditional downtowns, once the prime commercial properties, and many established neighborhoods[lii] (Arrington, 2003).

This model assumes a comparable shift towards TOD in an oil constrained future, driven by market forces related to extremely high oil prices and pre-existing unmet demand. Today, zoning often inhibits the rapid development of TOD and the model assumes that any new Urban Rail transit would have complementary zoning for TOD attached. No punitive measures, such as tolling existing freeways, extremely high fuel taxes or risk premiums on suburban mortgages are assumed in the model, but the model also assumes no governmental subsidies or policies to resist changes to a more energy efficient urban form as the market demand changes.

Results of the simulation

T21 is a computer-based national development planning models consisting of a set of dynamically integrated sectors with a causal-descriptive System Dynamics based simulations with time delays, feedbacks and non-linear interactions that together would be adequate to represent the long term development of most countries, industrialized and developing[liii] (Millennium Institute, 2005). This model is designed to support national development planning and has been applied to over 25 countries over the last 15 years. A more detailed description of T21-USA is available[liv] [lv] [lvi] (Bassi, 2008; Bassi, 2007; Millennium Institute, 2005). The use of the Threshold 21 model customized to the United States helps understanding, through the contextualization of energy issues and mitigating measures, and quantifying the impact of electrifying urban and freight rail as a mean to reduce oil consumption in the US using known and mature technology. This exercise answers, among others, the concerns raised by Brown and Huntington, that consider national security, climate change and energy issues as competing problems that may require different solutions[lvii] (Brown and Huntington, 2008).

The main results of the market based reference scenario can be summarized as follows. Energy prices are among the main factors affecting GDP as oil prices increase. Therefore when oil production turns downwards in 2011 at 29.5 Mb/year, real oil prices jump to $315 per barrel (in year 2000 dollars) while GDP declines by 9%. This economic decline plus very high prices drive a reduction in energy demand (-5%), which makes oil prices decline to $180 in 2014. This factor, as observed in 1983 and 1984, allows a more energy efficient economy, where energy conservation has taken place, to grow until energy prices start increasing again. In fact, the GDP growth rate turns positive in 2014 and oscillates around zero (despite growing population) until the energy transition is fully completed by 2025 (Figure 2a). Over the longer term, though demand is rapidly decreasing following declining supply, oil prices will keep increasing due to the higher cost of extracting oil from less accessible reservoirs, reaching $375 in 2050. In fact, the energy return on energy invested for oil and gas is projected to decline, reaching a ratio lower than 10:1 in 2050 for economically producible oil wells[3].

When simulating the Transportation scenario in isolation, the electricity needed to power urban and freight rail increases from 0.0265 Quads (quadrillion Btu) in 2007 to 0.34 in 2025 and 0.43 in 2050, contributing to the growth of electricity demand (+7% in 2025 and +52% in 2050 with respect to the baseline scenario). Most of this increase would come from increased general economic activity and little from electrified rail. In fact, Real GDP at market price is projected to rise to $19.6 trillion in 2050 (+64% with respect to the reference case) in the Transportation scenarios, due to a reduced dependency on oil. This electricity, in the market base case, will generally be obtained by burning coal, the cheapest energy source for electricity generation. Though coal is less expensive than oil, its impact on the environment is a much more destructive. Emissions, in fact, increase to 4.7 billion tons in 2050 (-3% in 2025 and +24% in 2050 compared to the reference simulation), while coal consumption grows by 50% in 2050 with respect to the base case. When simulating the Transportation scenario, the average energy price declines and is constantly lower than in the Market Based case starting from 2020 and throughout the end of the simulation (-16% in the Transportation scenario and -18% when the renewable case is simulated, in 2050).

The cost for the creation of an improved electrified rail sectors is estimated to amount about $1.7 trillion over the next 20 years. These combined investments represent 10% of GDP in 2007 and are lower than the projected avoided cost in 2030 already, that is they will have no net cost to the economy over a 20 years time frame. In addition, they are about 80% of total investment in 2007 or about 4% of the

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[3] For a more detailed explanation of the potential implications of declining EROI see L. Gagnon, Civilisation and energy payback, Energy Policy, 2008.

projected total investment, both private and public, for the period 2010 – 2030 (34% if only consider public investment).

When simulating the Renewable scenario in addition to the Transportation case, the increasing need for electricity is generated with renewable sources. The power generation from renewable sources equals 4,800 billion Kwh (a value 12 times higher than in 2007), representing 58% of total energy demand in the US in 2050 or 70% of 2007 demand. In fact, this simulation shows a considerable increase in electricity demand and a diversification of supply. As a consequence, electricity cost increases -both for the increasing demand and for the utilization of more expensive sources (+80% in 2050 with respect to the Reference case). The increase of electricity prices is a side effect that limits the expansion of electrified rail use, as shown by the decline in electricity demand for rail (-15% and -20% with respect to the transportation case in 2025 and 2050 respectively). Nevertheless, the high price paid for electricity, about $800 billion in constant 2000 USD (+25% with respect to the transportation case, or $150 billion) is generally offset by the savings generated by a reduced consumption of oil and more expensive fossil fuels as shown by a higher GDP (+75% in 2050 and +6% when simulating the Renewable scenario in isolation). Interestingly, this scenario also shows that a reduced consumption of coal for electricity generation in the US until 2030 will lower coal prices, leading to an increase in coal use by heavy manufacturing sectors, which is also coupled with lower oil use and higher GDP. Higher GDP though requires more electricity (see Figure 1a), which is mainly obtained by burning coal after the RPS goals are met after 2035 (see Figure 1b). Policies aimed at reducing carbon emissions, such as the cap-and-trade proposals of US Senators Bingaman-Specter (S.1766[lviii]) and Lieberman-Warner (H.R. 2191[lix]) would help reducing the come back of coal and the consequent increase in carbon and GHG emissions visible after 2035 in Figure 2.

The combination of these scenarios shows how important well planned energy policies and synergies among the energy segments can be when facing challenges in both the energy and environmental sectors.

Figure 1a and 1b: historical data and projections for electricity demand -BKwh/yr- (1a) and CO_2 emissions -Ton/yr- (1b).

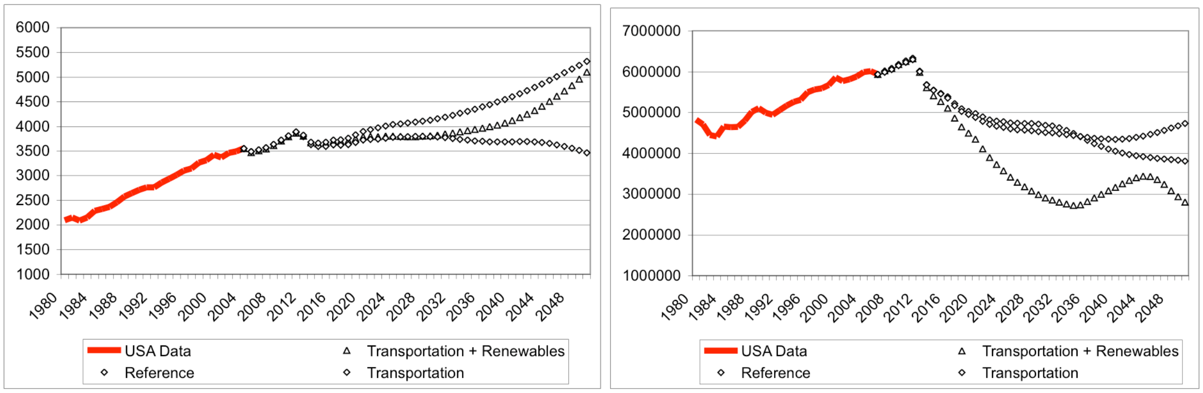
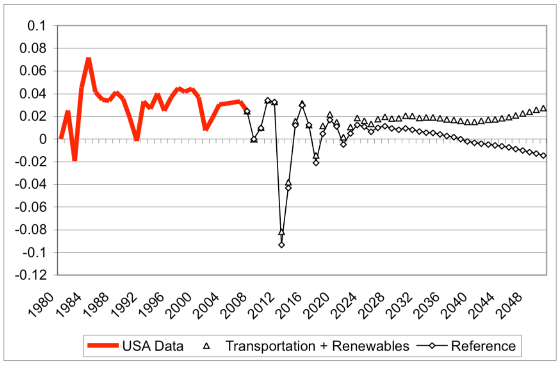
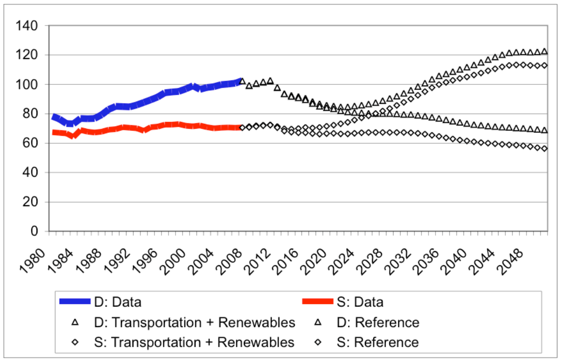


Figure 2a and 2b: historical data and projections for GDP growth rate (2a) and energy demand/supply -Quads/yr- (2b).





The behavior description and analysis of the Transportation and Renewables scenarios concentrate on energy and its interconnections with the three other sectors: society, economy, and the environment.

Society

Total population in the USA is projected to grow by 32.6% in the period 2007 – 2050, reaching 402 M, in line with projections from United Nations Population Division. Population growth in the US, especially for the elderly age cohorts, is likely to affect the sustainability of social security and medicare trust funds as indicated by the increase in their share of the population in the breakdown by age cohorts. Employment is projected to remain about constant through 2050 (140 M) and increases to 170 M and 175 M in the Non Oil Transportation and Non-Oil Transportation plus Renewables scenarios respectively. The USA of 2030 and 2050 in the base line scenario is one of lower incomes and labor intensive employment (due to high fuel prices) coupled with high unemployment, comparable to nations transitioning from a developing to an industrial economy.

No effective mitigation measure for Climate Change are assumed, with probable impacts increasing towards 2050. Comparatively higher oil use will likely affect foreign policy and one can foresee considerable external pressures on future policy makers. The Non-Oil Transportation plus Renewables USA has an economy slightly better than today by 2030 already, after having gone through a difficult, and now unavoidable, transition period.

Economy

The main components of the Economic sector included in T21-USA are related to the four agents acting in the USA economy: producers, government, households, and the rest of the world (ROW)[lx] (Drud et al., 1986).

Real GDP at market price in the base case is projected to remain at about its current level in 2050 ($12 trillion, using 2000 as the constant dollar base year) and rise to $19.6 trillion (+64%) in the Transportation and $21 trillion (75%) in the Renewable scenarios, due to reduced dependency on oil (see Figure 2a). Per Capita GDP follows the behavior of GDP, and households savings are reduced by the increasing energy cost and increasing taxation (applied to keep government debt at acceptable levels), especially in the reference case. The projections of T21-USA show that investing in renewable energy and more efficient transportation reduces energy expenses in the medium to longer term and makes income increase. The elasticity of GDP to energy prices is assumed to be a function of the overall energy intensity of the economy. This means that the economy becomes less and less sensitive to energy prices as its efficiency increases. Elasticity in 1980 is set to -0.3, the lowest value among various estimations dating back to the highly volatile early eighties[lxi] [lxii] (Gately, 2004; Brown, 2003) and reaches -0.12 in 2050.

Nominal Federal government revenues and expenditures generally follow the GDP trend, as the former are obtained through taxation and the latter are allocated based on available revenues. As a consequence, the overall fiscal balance (i.e. revenues minus expenditure) will remain negative throughout the simulation, reaching $4 trillion in 2050. The continuing deficit will lead to a steady increase in public debt (two times higher than GDP in 2050) and as well as the share of government expenditures allocated to debt service.

Energy and Environment

Total energy demand projections by the USA indicate very different trends for the different scenarios. Demand ranges between 70 and 122 Quads in 2050, with the former referring to the baseline scenario (the transportation scenarios alone results in demand equal to 80 Quads) and latter regarding the simulation of interventions in both the transportation and power sector. The projected dependency on foreign energy decreases for both scenarios, especially when combined transportation and renewable investments are allocated (see Figure 2b). Crude oil dependency is projected to increase from 65% in 2005 to 70% in 2011 and then decline to 37% in the Transportation and Renewable scenarios by 2050 (62% in base case).

While total World CO_2 emissions are projected to increase throughout the simulation, with the only the exception of a few years following peak oil, U.S. emissions decline in all scenarios by 2050 (reaching about 3.5 Billion Tons per year, -40% with respect to 2006 and well below 1990 levels).

Conclusions

The world, including the United States of America, is facing an oil constrained future and a plethora of public policy options are being considered. The authors used the Millennium Institute's T21-USA model to evaluate several policy options and combinations of policies.

One public policy approach that was evaluated has been rarely considered in the USA, is the creation of a Non-Oil Transportation system in parallel to the existing Oil Based Transportation system. Other nations, such as Switzerland and Sweden, were able to continue to function despite a six year, 100% oil embargo during WW II. Today France is deeply committed to creating a comprehensive Non-Oil Transportation system, from rental bicycles, walkable communities, thousands of km of new tram lines, with trams in towns of 100,000 to new TGV lines, but this approach is seldom considered in US policy debates. Constraints prevented the modeling of increased bicycling use in the USA, or increased medium and long distance electrified passenger train travel, so only an expanded and electrified freight railroad system coupled with an expanded Urban Rail system with associated Transit Orientated Development was modeled.

The initial modeling results from the Electrified Rail component of Non-Oil Transportation were quite positive, and a virtuous synergy was found when Electrified Rail was coupled with a push for Renewable Energy. Projections indicate that generating the increasing need for electricity, due to massive rail electrification, with renewable energy instead than coal generates optimum results for the major metrics considered: GDP, Greenhouse Gas Emissions and Oil Consumption. The simulation of the model also show that elements of policy resistance may arise due to increased electricity price and reduced coal prices, and that attention should be paid to implementing policies that would allow the economy to become less energy intensive after goals for RPS and electrification are met.

A new paradigm appears to be evolving from this work. Public policy goals that were once considered contradictory can be, in fact, complementary. The best economic policy can also be the best energy policy, as well as the best environmental policy and best national security policy already in the short and medium term, when considering an oil constrained scenario. Previously competing interests and stakeholders could find a common policy to unite behind for quite disparate reasons and with fundamentally different priorities. A major change in energy public policy may develop in the USA and elsewhere. Acknowledging that it is not possible to pursue every possible option with a maximum commercial effort, if a crisis in energy develops, the Millennium Institute T21-USA is a useful tool to discern which policy options should be emphasized, and which ones not.

Further work is needed to model the ignored elements of Non-Oil Transportation; bicycling and longer distance passenger train service and to expand the universe of policy alternatives evaluated.

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