# Shipping to Streaming: Is this shift green?

Manikandan Somasundaram, Anand Seetharam, Jim Kurose, Don Towsley, Prashant Shenoy
{*mani, anand, kurose, towsley, shenoy*}*@cs.umass.edu*

Department of Computer Science
University of Massachusetts, Amherst MA 01003, USA

## ABSTRACT

Streaming movies over the Internet has become increasingly popular in recent years as an alternative to mailing DVDs to a customer. In this paper we investigate the environmental- and energy-related impacts of these two methods of movie content delivery. We compare the total energy consumed and the carbon footprint impact of these two delivery methods and find that the non-energy optimized streaming of a movie through the Internet consumes approximately 78% of the energy needed to ship a movie, but has a carbon footprint that is approximately 100% higher. However, by taking advantage of recently proposed "greening of IT" techniques in the research literature for the serving and transmission of the movie, we find that the energy consumption and carbon footprint of streaming can be reduced to approximately 30% and 65% respectively of that of shipping. We also consider how this tradeoff may change in the future.

## 1. INTRODUCTION

With the increasing deployment of broadband connectivity, online movie streaming is becoming increasingly popular, with many predicting that streaming will replace more traditional mail-based shipping of movies. Some companies (e.g., Netflix) provide both delivery methods. With streaming service, a customer selects a movie and is then able to view the movie immediately as it is streamed from Internet-connected servers to the customers display device. With mail-based delivery, a customer orders a movie online, and the movie (in DVD form) is then mailed (shipped) to the user, who later returns the DVD via mail. Although mail delivery of DVDs is currently more popular, online streaming is gaining popularity [15, 16].

There is currently considerable interest in both using information technology (IT) to "green" other industries and in "greening" the IT infrastructure itself. Movie content delivery offers a case study that illustrates and quantifies the potential of both of these opportunities. In this paper we quantify the amount of energy consumed and environmental impact (carbon footprint) of two methods for movie delivery (traditional DVD mail delivery versus on-line streaming), allowing us to determine the extent to which streaming can green this service. We find that non-energy optimized Internet streaming consumes approximately 78% of the energy needed to ship a movie, but has a carbon footprint that is approximately 100% higher.

Considering recently proposed methods for decreasing energy use in data centers and networks, we find that the energy consumption and carbon footprint of streaming can be reduced to approximately 30% and 65% respectively of that of shipping  making streaming delivery even more attractive, but still not overwhelmingly so. Lastly, we also consider longer term trends in both content itself (e.g., increased size, with 3D high-def movies) and potential changes in both network and mail-based delivery. Here we find that greening gains decrease, as the amount of data associated with a movie increases.

As a case study, this work reminds us that IT  even greened IT  is not always a panacea for significantly greening traditional industries, despite the rather intuitive appeal of delivering data via a gleaming, modern IT infrastructure versus a traditional bricks, mortar, and roadway system. The energy- and environmentally-related benefits to be had are modest and only in certain areas of the movie-content delivery service design space. However, our results do point to the fact that there are such indeed benefits to be had, and quantifies the extent to which ongoing research efforts in greening IT data centers and Internet infrastructure can be used to realize, and increase, these benefits.

The remainder of this paper is organized as follows. §2 overviews related work. We describe shipping and streaming delivery methods and assumptions about movie viewing in §3. We quantify the energy consumed in the shipping and the online streaming cases in §4 and §5 respectively. We present the carbon footprint and evaluation results in §6 and §7 respectively. We discuss the results in §8, and conclude in §9.

## 2. RELATED WORK

Several recent studies have compared the environmental impact of online versus retail store purchases.

In [39], the authors compare the environmental impact of renting a DVD from Blockbuster with that of ordering a DVD from Netflix. The environmental impact of online versus retail purchase of electronics was examined in [42]. Both [39] and [42] observe that the online option is advantageous from the environmental standpoint. [45] provides more mixed results, noting that in urban areas, online purchases consume more energy, while in rural areas the two options have similar energy consumption.

In [43], the authors compare the energy cost and carbon footprint of Internet-downloading of songs versus traditional retail purchasing of a CD. Part of their analysis is a calculation of the energy spent in transmitting a bit of information. The analysis in [21] compares the dollar (not energy) costs of sending a large amount of data over the Internet versus shipping the same data via mail; the focus of our paper is on the energy and environmental costs of two methods of movie content delivery, and the schemes that can be used to green these methods.

Nano Data Centers [41] is a distributed computing platform that the authors argue can save approximately 20-30% in energy compared to traditional data centers for VOD services. In contrast, this paper compares the energy and environmental costs of traditional data centers with mail delivery, considers both manufacturing and transmission energy costs, and also estimates the carbon footprints. The savings envisioned in Nada could be realized by replacing the data center VOD services that we consider with Nada distributed services.

## 3. SHIPPING AND STREAMING DELIVERY METHODS

In this section we describe the infrastructure and energy consumption/carbon footprint model of shipping a DVD via mail versus streaming a movie through the Internet. For assessing the energy and environmental costs1 in shipping a DVD, we consider Netflixs DVD mail-delivery service as a representative example [39]. The costs of manufacturing the various components involved in shipping (DVDs, packaging, trucks) operating the distribution centers, and transporting the DVDs are determined and added to determine the cost of delivering a single DVD.

In the streaming case, costs are incurred in transmitting the movie over the Internet and in manufacturing the various equipment involved in streaming. The costs of recycling are also taken into account (both for streaming and mail delivery). We calculate these costs and amortize them appropriately in estimating the cost of a single streaming of the movie. We perform these calculations assuming two scenarios  a non-energy optimized scenario (roughly, using todays technology and operating at peak power ratings at all times, even when idle) and an energy-optimized scenario (where recent research results for decreasing the energy consumption of data centers and networking are taken into account). The parameters used in our calculations are given in Table 1.

| | **Description** | **Value** |
|---|---|---|
| $S$ | Size of Movie | $8 * 8 * 10^9$ bits |
| $D$ | Duration of Movie | $2 * 3600$ seconds |
| $N$ | # Movies streamed in a day | $2.2 * 10^6$ |
| $R$ | Recycling Factor | 0.87 |
| $L$ | Lifetime of IT equipment | 3 * 365 days |
| $T$ | # Movie Titles [15] | $10^5$ |

**Table 1: Parameter values used in assessing cost**

Once the movie has been delivered to the customer (whether by mail or via streaming), the customer watches the movie on a laptop or display device such as a flat panel TV. The total energy cost of watching a movie on a laptop and television are 2.788MJ and 5.44MJ respectively (refer Appendix). As these costs are common to both shipping and streaming we will not consider these costs further. We note here, however, that these costs are larger (by a factor of roughly 3 to 5) than the delivery costs discussed in the remainder of the paper, making display costs the dominant factor in viewing in-home movies.

## 4. ENERGY SPENT SHIPPING A DVD

For evaluating the energy costs for shipping a DVD we use data provided in prior work [39]. After the DVDs are manufactured, they are first transported to the main distribution center in Sunnyvale, California [39]. Then the DVDs are put in plastic cases and trucked to the various regional warehouses. We assume this distance as 3800Km [39]. The weight of the DVD is 18g and the weight of the plastic case is 85g [39]. Once at the regional warehouses, DVDs are shipped to customers on request, and returned to the warehouse by the customer, until the life of the DVDs expire. The reusability of DVDs is taken as 12 [5]. For this last-leg-shipping between the warehouse and customer, DVDs are removed from the plastic case and transported in a custom-made paper sleeve. The approximate weight of the DVD with paper sleeve is 21g. This last-hop transportation is assumed to be done by a truck, with a round trip distance is 210Km [39].

### *Warehouse*

Any company which ships movie DVDs to people living in different parts of the country most have distribution centers spread throughout the country. We consider the number of number of regional distribution centers to be 55 [24]. The area of each distribution center is assumed to be 20000sq ft [26]. The area of the main warehouse from which these DVDs are dispatched is assumed to be

79000sq m [39]. The values of annual energy consumption per sq ft was determined from [1, 14]. Using these values and considering that a total of 2.2 million DVDs will be shipped in a day from the 55 distribution centers and main warehouse, we determine the total energy consumption that needs to be attributed to the single shipping of the DVD is 0.069MJ.

### *DVD*

We assume that the paper sleeves and plastic cases used for DVD packaging are recycled [2]. The energy savings when paper and plastic are recycled are about 64% and 80% respectively [3]. Since we could not find the energy savings of DVD recycling, we assume that it is 13%, as with other IT equipment [38]. Using these recycling factors, we estimate the marginal energy cost incurred in manufacturing a DVD, plastic case and paper sleeve for a single shipping of a DVD to be 0.976MJ, 0.125MJ and 0.1764MJ respectively [14]. We have amortized the manufacturing cost of the DVD and the plastic case over the reusability of the DVD.

### *Transportation*

We assume that a 20000lb (9060kg) delivery truck is used for transportation. We assume that the truck has a energy efficiency of 18MJ/mile [43, 29] and the lifetime of the truck is 155000 miles [8]. The energy spent in the transportation of the DVD (with plastic case) to the distribution center which should be attributed to a single shipping is

$$\frac{103 * 10^{-3}}{9060} * 2361 * 18 * \frac{1}{12} = 0.0403\text{MJ}$$

and the energy spent in the last leg of the transportation to the customer is

$$\frac{21 * 10^{-3}}{9060} * 130.49 * 18 = 0.0054\text{MJ}$$

The total cost of manufacturing the truck is 200932 MJ (refer Appendix). The fraction of manufacturing energy of the truck, which should be associated with shipping a movie once is

$$\begin{aligned} &\frac{103 * 10^{-3}}{9060} * \frac{2361}{155000} * \frac{200932}{12} \\ &+ \frac{21 * 10^{-3}}{9060} * \frac{130.49}{155000} * 200932 \\ &= 0.0033\text{MJ} \end{aligned}$$

Table 2 summarizes the energy consumption of the various steps associated with mail-based DVD delivery. Note that the energy consumption of DVD manufacturing accounts for 70% of the overall energy cost.

| | **Transportation Energy** | **Manufacturing Energy** | **Total Energy** |
|---|---|---|---|
| Warehouse | 0 | 0.069 | 0.069 |
| DVD | 0 | 0.976 | 0.976 |
| PlasticCase | 0 | 0.125 | 0.125 |
| PaperSleeve | 0 | 0.1764 | 0.1764 |
| Truck | 0.046 | 0.0033 | 0.0493 |
| Total | 0.046 | 1.35 | 1.396 |

**Table 2:** **Energy costs: DVD Shipping Method (in MJ)**

# 5. ENERGY SPENT IN ONLINE STREAMING

In this section, we estimate the total energy consumed in streaming a movie via the Internet. In this scenario, a streamed movie originates from the data center, traverses a set of backbone and edge routers, and finally passes through the home router to reach the customer. The customer watches the movie on a display device. We assume the data center is provisioned to meet a peak demand of 2.2 million requests (based on the fact that Netflix currently ships 2.2 million DVDs per day [15] and most movies are watched between 6 pm and 12 am).

We consider two scenarios a non-energy optimized scenario (roughly, using todays technology and operating at peak power ratings at all times, even when idle) in §5.2 and an energy-optimized scenario (where recent research results for decreasing the energy consumption of data centers and networking are taken into account) in §5.3. We begin by considering manufacturing costs associated with a single streaming of a video, which are common to both scenarios.

## 5.1 Energy spent in equipment manufacturing

An exact analysis of the energy expended in manufacturing servers, hard drives and routers is not available in literature. Therefore we estimate these costs from data given in [44, 30]. Since manufacturing accounts for only 12% of the total energy cost (Table 3), even if our estimates differ from the actual values, they are unlikely to affect our overall conclusions. We again assume that 13% of the total energy expended in manufacturing IT equipment is recovered by recycling [38] and assume that IT equipment has a lifetime of 3 years [44], as noted earlier.

### *5.1.1 DataCenter and Routers*

**Storage:** We use to find the manufacturing energy cost of the data storage. The manufacturing cost of a disk drive of size 30GB was 2926MJ in 2000 (taking into account the manufacturing costs of semiconductors, silicon wafers, electronic chemicals, semiconductor manufacturing equipment, transport, packaging, disk drives and other parts) [44].

By Moore's law, the number of transistors that can be packed in the same area will double every 18 months. In 2000, 2926MJ was spent on a 30GB hard drive, and by application of Moore's law, in 2009, the same amount of energy will be spent on 2TB hard drive.

The manufacturing cost of a 1PB data data storage is 2926*500 = 1463000MJ. Now the fraction of the total manufacturing cost of this 1PB storage, which should be attributed to a single streaming of a movie is

$$\frac{1463000\text{MJ}}{L} * \frac{1}{N} * R = 0.000528\text{MJ}$$

**Servers:** We estimate the total energy expenditure in manufacturing a server from the total energy spent in manufacturing a desktop as 5345MJ, after excluding the manufacturing cost of the CRT monitor (The manufacturing cost of the desktop is 6400MJ, and the CRT monitor is 1055MJ)[44] .

The rate at which a server can serve requests is contingent upon how fast it is able to read data from the disk. The maximum sustained rate at which data can be read from the disk is 464 Mbps [22, 32]. Therefore, the total number of servers required to serve the peak load in Table 1 is

$$N_s = \frac{N(\frac{S}{D})}{464 * 10^6} = 42151$$

Therefore, the server-related manufacturing energy cost attributable to streaming a single instance of a movie is

$$\frac{5345 * N_s}{L} * \frac{1}{N} * R = 0.081\text{MJ}$$

**Routers:** To simplify the calculation of router costs, we assume that only M7i (edge router - 400W, 10Gbps) [12] and M40 (backbone router - 1600W, 40Gbps) [11] Juniper routers are involved in the streaming of the movie. To obtain the manufacturing energy cost of a router, we scale the value obtained for the desktop proportional to the weight of a router. We consider the average weight of a desktop (excluding display) to be 10Kg. The weight of the M40 router is 127Kg [11] while that of an M7i router is 17.3 Kg [12]. The average utilization of a router is considered to be 30% [37].

Hence the energy costs associated with the manufacturing a edge router which should be attributed to a single streaming of a movie is

$$\frac{17.3}{10} * \frac{5345}{L} * \frac{S}{(10 * 10^9) * 0.3 * 86400} * R = 0.0018165\text{MJ}$$

The manufacturing cost of a backbone router which should be attributed to a single streaming of a movie is

$$\frac{127}{10} * \frac{5345}{L} * \frac{S}{(40 * 10^9) * 0.3 * 86400} * R = 0.0033274\text{MJ}$$

We perform an upper bound calculation assuming that 15 routers are in the path [41]. Thus the fraction of the total manufacturing energy of the 15 routers in the path, which should be attributed for a single streaming of a movie is

$$0.0033274 * 15 = 0.05\text{MJ}$$

### 5.1.2 *Home Router*

For the home router too we do an analysis similar to the one done in the previous section. The weight of the home router is 0.482kg [13]. At present, the monthly median traffic flowing through a home router is 4GB [6]. If we assume that the subscriber streams 5 movies in a month, this would result in 40GB of traffic being generated by movie streaming alone. If we were to amortize the manufacturing cost of the home router on the basis of total traffic flow, we would assign almost the entire manufacturing cost of the home router to movie content alone; this seems unreasonable. Thus, instead of attributing cost based on number of bits transmitted, we instead attribute costs as a percentage of time used for a given service. Under this cost-assignment model, the manufacturing energy cost is

$$\frac{0.482}{10} * \frac{5345}{L} * \frac{D}{86400} * R = 0.0177\text{MJ}$$

Note here that the manner in which costs are assigned (per-bit versus per-time-unit-of-use) can result in very different energy cost estimates.

## 5.2 Non-energy optimized transmission

In this subsection we evaluate the energy consumed in transmitting the movie through the Internet in a non-energy optimized scenario. For this case we perform all calculations considering the peak power ratings and assuming that the power consumed by idle equipment is equal to the power consumed in the active state.

### 5.2.1 *Data Center and Routers*

To store $10^5$ titles each of size 8GB, we assume a 1PB storage is used. A conventional PB storage consumes 864.2kW [25]. Hence the total energy consumed by the storage in a day is $864.2 * 10^3 * 86400$ J. Therefore, the energy which should be attributed to a single streaming of a movie is

$$\frac{864.2 * 10^3 * 86400}{N} = 0.03393\text{MJ}$$

For analyzing the total energy spent by the servers, we consider the model of a typical server given in [32, 7]. The specification of the typical server is given in Table 3. Assuming a power supply efficiency of 85%, the peak power consumption for the typical server is 251W [32]. The total energy consumed by a server in a day is $251*86400*10^{-6} = 21.68$MJ. Therefore, the total energy consumed by the servers for a single streaming of a movie is

$$\frac{21.68 * N_s}{N} = 0.415\text{MJ}$$

| Component | Power in Watts |
|---|---|
| CPU | 80 |
| Memory | 36 |
| Disk | 12 |
| Peripheral slots | 50 |
| Mother board | 25 |
| Fan | 10 |
| Total | 213 |

**Table 3:** **Configurations of a Typical Server**

The servers and storage are dedicated and so the total energy cost required for operating the servers and storage in a day is split evenly among the 2.2 million movies streamed during the day.

For routers, the total energy consumed is the sum of the energy required to transmit the 8 GB movie and the idle state energy amortized over the total traffic flowing through the router in a day. To simplify our calculations, we assume that only M7i [12] and M40 [11] Juniper routers are involved in the single streaming of the movie. The M40 is an Internet Backbone Router, while the M7i is an edge router. The M7i can also be used as enterprise router. The M7i router has a power rating of 400W and it can transmit at 10Gbps. Thus, the total energy required for transmitting a 8GB movie is

$$\frac{S}{10 * 10^9} * 400 = 2560\text{J}$$

A similar calculation for the M40 router (1600W, 40Gbps) gives the same value of 2560J for transmitting a 8GB movie.

The idle state energy which should be attributed to the movie is

$$\text{Total idle state energy} * \frac{\text{Size of movie}}{\text{Total traffic through router}}$$

We consider the router utilization to be 30% [37]. Hence, the energy spent in idle state for the movie by M7i as well as M40 is

$$0.7 * 400 * 86400 * \frac{S}{0.3 * 86400 * (10 * 10^9)} = 5973.33\text{J}$$

As we are considering a non-energy optimized scenario, we assume the total number of routers in the path to be 15 (excluding home router) [41].

Based on the calculations the total energy spent by all the routers for streaming a movie once is

$$(2560 + 5973.33) * 15 = 0.128\text{MJ}$$

Just as our analysis of DVD mailing had warehouse overhead costs, so too must data center operating and overhead costs (e.g., cooling) be taken into account. To incorporate the cooling and infrastructure costs for the above equipment, we assume a Power Usage Effectiveness (PUE) of 1.5. The values in Table 4 are obtained by scaling the transmission energy costs we discussed earlier for storage, servers and routers by this PUE value of 1.5.

### *5.2.2 Home Router*

We consider the home router to be a Linksys Wireless Broadband Router (12 W) [5]. As in our earlier analysis of manufacturing costs of the home router, we amortize the transmission costs of the router on a per-unit-of-time (rather than per-bit) basis. In this case, the energy spent in receiving the streaming movie for 2 hours is

$$12 * D = 0.0864\text{MJ}$$

Combining the entire set of data, the total energy spent in a single streaming of a movie (including manufacturing) is 1.1 MJ. Table 4 summarizes the results of this section. As can be seen, this value is lower than the 1.39 MJ cost for shipping, computed in Table 2.

## 5.3 Energy-optimized transmission

In this subsection, we evaluate the potential savings when various greening strategies are used to decrease the energy consumption of transmission. Since storage consumes a negligible fraction of the total energy, we do not discuss the greening of storage.

### *Green Datacenter*

A two-fold approach can be taken to make datacenters more energy-efficient. First, IT equipment can be made (or operated) in a greener manner. Secondly, the energy spent in cooling and infrastructure (as reflected in the PUE) can be decreased.

Although today's servers are non-energy proportional, the benefits of energy-proportional equipment have been widely advocated, e.g., [32, 28]. We thus expect that in the future, server power consumption will reflect server utilization. Server utilization levels typically lie between 10-50% [28]. For a conservative estimate of the energy savings with energy-proportional servers, we assume a 30% server utilization and that idle energy-proportional machines consume 10% of the power consumed in the active state.

The reduction of the PUE of data centers has considerable attention. [33] identifies best practices to decrease the PUE. Using energy-efficient methods, Google has reduced the PUE from 1.5 to 1.1 [9] in some of its data centers. Indeed, one can even reduce the PUE below 1 by locally generating power from waste heat (although we do not consider this option here). In computing costs for energy-optimized energy transmission, we will assume a PUE of 1.1.

### *Green Networking*

Networking devices, like servers, are often under-utilized, and substantial savings can be obtained by sleeping and link-rate-adaptation [37, 36]. Sleeping reduces the energy consumption in the idle state, while link-rate adap-

|  | **Transmission Energy** | **Manufacturing Energy** | **Total Energy** |
|---|---|---|---|
| DataStorage | 0.051 | 0.000528 | 0.0515 |
| Servers | 0.6225 | 0.081 | 0.7035 |
| Routers | 0.192 | 0.05 | 0.242 |
| HomeRouter | 0.0864 | 0.0177 | 0.1041 |
| Total | 0.9519 | 0.15 | 1.1 |

**Table 4: Energy Costs: Non-energy Optimized Streaming Method (in MJ)**

|  | Streaming (Non-energy optimized Transmission) (MJ) | Streaming (Energy optimized Transmission) (MJ) |
|---|---|---|
| DataStorage | 0.051 | 0.0374 |
| Servers | 0.6225 | 0.169 |
| Routers | 0.192 | 0.036 |
| HomeRouter | 0.0864 | 0.0223 |
| Total | 0.9519 | 0.265 |

**Table 5: Energy savings (MJ) with green transmission**

tation decreases active state and idle state energy consumption. [37] demonstrates that by using a buffer-and-burst approach to realize wake-on-arrival schemes on high-speed links, a 20-30% savings can be obtained. Similarly, using rate adaptation and Dynamic Voltage Scaling, the energy savings can be as high as 50% [37]. As discussed above, assuming that equipment operates with energy-proportional costs (with idle state power costs of 10% of the active-state power) and applying a conservative additional reduction in energy of 30% obtained by sleeping and rate adaptation, router energy consumption (including the home router) can be reduced from 0.278 to 0.06. Additional energy-reduction approaches, such as consolidation of network traffic [34], using light-weight switches in parallel with high-power switches [27] have also been suggested to decrease energy consumption.

Table 5 summarizes the gains that can be obtained by adopting the greening options discussed above. With these optimizations, the energy costs of optimized transmission are only 28% of the costs of non-energy optimized transmission.

## 6. CARBON FOOTPRINT

To determine the carbon footprint of various delivery mechanisms, we determine the amount of carbon dioxide emitted due to shipping and streaming a movie. The carbon footprint is the product of the carbon dioxide emission coefficient and the energy consumed. We use the mean value of carbon coefficient for electricity (1.297lbs/kWh) [5] in our calculations. We note that in some locations, e.g., where the primary source is hydroelectric supplemented by nuclear, the carbon footprint of electricity generation can be 95% lower than this carbon loading e.g., [10]. These significant reductions, however, would be shared by both forms of delivery.

We also note that some amount of carbon would also be recovered due to recycling. From [35] we observe that the carbon cost recovered due to recycling for a laptop is approximately 13%. Due to unavailability of date we apply this same value to all IT equipment as well the DVD. Exact figures for the reduction in carbon cost due to recycling of paper and plastic vary among different sources [23, 46, 18, 20]. So we assume the recycling benefits for carbon to be same as that of energy.

### 6.1 Shipping

*Warehouse and DVD*

The total carbon footprint of the warehouse that needs to be attributed to the single shipping of the DVD is

$$\frac{1.297 * 453.6}{3.6} * 0.034 = 11.27g$$

The carbon dioxide emissions associated with manufacturing of the paper sleeve, plastic case and DVD are 8.82g, 6.26g and 48.84g respectively [39]. Hence the manufacturing carbon cost of a DVD and its packaging is 63.92g.

*Truck*

[40] and [31] determine the energy consumption and carbon footprint for manufacturing a mid-size US built passenger car respectively. The weights of the car assumed in both cases are approximately the same. We scale these values to determine that the carbon footprint for manufacturing a 20000lb truck as 25666kg.

Hence the total carbon footprint of manufacturing a truck that has to be associated with a single shipping of the DVD is

$$\begin{aligned} &\frac{103 * 10^{-3}}{9060} * \frac{2361}{155000} * \frac{25666 * 10^3}{12} \\ &+ \frac{21 * 10^{-3}}{9060} * \frac{130.49}{155000} * 25666 * 10^3 \\ &= 0.42\text{g} \end{aligned}$$

The carbon footprint of the truck usage is 2.95g [39] and thus the total carbon footprint associated with the truck is 3.37g. Since the carbon footprint associated with truck manufacturing is very small, we ignore the recycling benefits that can be obtained from truck recycling.

### 6.2 Streaming

We estimate the carbon footprint IT equipment from the values obtained for a laptop and a server like stand alone computer. The carbon footprint of manufacturing a laptop weighing 1.5kg is 150kg [35]. A stand alone computer which weighs approximately 20Kg has a carbon footprint of 500 Kg [35]. We perform these calcu-

|  | **Streaming (Non-energy optimized transmission)** | **Streaming (Energy optimized transmission)** | **Shipping** |
|---|---|---|---|
| Storage | 8.4 | 6.29 | n.a. |
| Servers | 104 | 29.88 | n.a. |
| Routers | 33.77 | 8.329 | n.a. |
| HomeRouter | 14.85 | 4.44 | n.a. |
| Warehouse | n.a. | n.a. | 11.27 |
| DVD | n.a. | n.a. | 48.84 |
| PaperSleeve | n.a. | n.a. | 8.82 |
| PlasticCase | n.a. | n.a. | 6.26 |
| Truck | n.a. | n.a. | 3.37 |
| Total | 161.02 | 48.939 | 78.56 |

**Table 6: Carbon Footprint (in g)**

lations in a similar way that we did for determining the energy cost of manufacturing the various equipment.

*Data Center and Routers*

The carbon footprint associated with manufacturing that should be associated with a single streaming is 0.054g. And the carbon footprint associated with usage of storage in non-energy optimized and energy optimized transmissions are 8.3g and 6.2g.

The carbon footprint of server manufacture that should be attributed to a single streaming of a movie is 2.28g. The carbon footprint of the server usage in the energy optimized transmission and non-energy optimized transmission that should be attributed to a single streaming of a movie are 27.6g and 101.7g respectively.

We scale the carbon dioxide emissions for manufacturing the stand alone computer in proportion to the weight of the router. Hence the carbon dioxide emission for manufacturing the M40 router that has to be attributed to a single streaming of the movie is 0.184g while that for an M7i router is 0.096g.

We perform an upper bound calculation by assuming 15 routers in the path of streaming. Thus the carbon footprint of manufacturing which should be attributed to a single streaming of a movie is 2.4g. The carbon footprint of router usage that should be attributed to a single streaming of a movie are 31.37g and 5.93g in the non-energy optimized and energy optimized transmission scenarios respectively.

*Home Router*

For the home router we determine the carbon cost of manufacturing by performing a weighted scaling of the carbon footprint of the computer. The manufacturing carbon cost of a home router that we attribute to a single streaming of the movie is 0.79g and that of usage is 14.054g and 3.65g in the non-optimized and optimized transmission cases respectively.

# 7. RESULTS

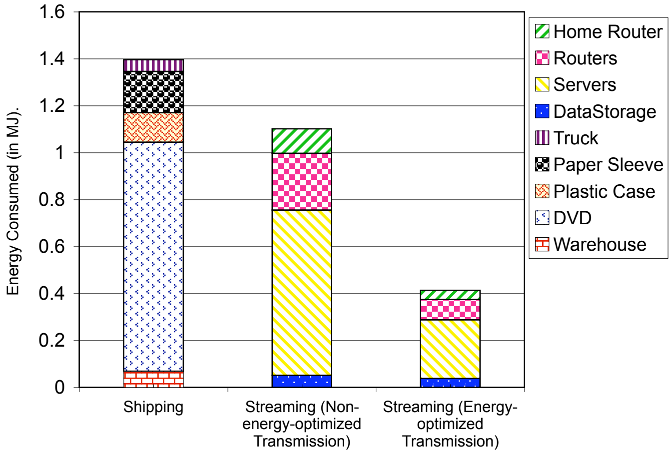

**Figure 1: Energy Consumption for Shipping vs Streaming**

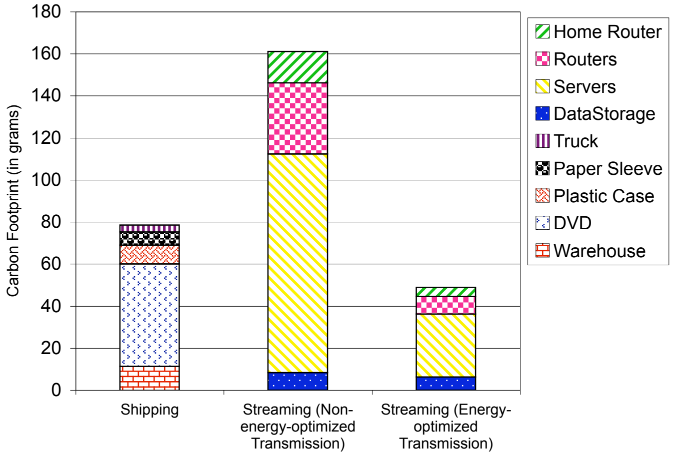

**Figure 2: Carbon Footprint**

Figures 1 and 2 summarize the energy consumption and carbon footprint costs of streaming and shipping. We observe that the energy consumption of streaming with non-energy-optimized transmission is 78% of that of shipping. However, the carbon footprint of streaming for the non-energy-optimized transmission is approximately 205% of that of shipping. However, when energy-optimized transmission is used, the energy consumption of streaming can be reduced to 29% of that of shipping, while the carbon footprint for this scenario reduces to 63% of that of shipping. Thus, by using greening techniques one can obtain substantial savings in energy as well as carbon footprint.

# 8. DISCUSSION

Our analysis thus far has considered current and near-term-future energy consumption scenarios. What might the longer-term future bring?

### *Higher-data-rate movies*

One can already have a superior viewing experience using Blu-Ray, with the size of Blu-Ray discs ranging between 25 and 50 GB. With viewers watching 3-D at home, we can imagine future movie sizes of 150 GB. If we assume the energy cost of manufacturing a Blu-Ray to be similar to that of a DVD, then since Blu-Ray discs have the same form factor as DVD, the energy costs of shipping will likely remain approximately the same. However this would not be the case with streaming, where the increased data sizes would result (using the same methodology as above, only assuming a higher data rate) in a per-movie energy cost in an energy-optimized scenario of 7.7MJ, making shipping significantly more energy-efficient than streaming delivery. In this scenario, the per-transmitted-bit costs of servers and routers would need to drop by a factor of 6 for the energy costs of streaming and shipping to remain comparable.

### *Multiple views*

Some customers might want to watch movies multiple times. This would not incur any additional environmental cost in the shipping scnario, as the customer can watch a movie multiple times before returning the DVD. However, in the streaming case, the same movie would need to be streamed multiple times, since local storage at the display device is currently not allowed. It is possible, however, that encrypted local storage and key-based access could be used in the future to allow multiple views of streamed content at no additional energy cost.

### *Greener Shipping*

We have focused much of our attention on greening streaming movie transmission. One can similarly argue that transportation will be greened in the future as well, e.g., by using green vehicles. It is also possible for the movie service provider to obtain licensing so that DVDs could be reproduced onsite. If ship-to-burn were to be the case, there would be no need for the DVDs to be shipped from the distribution centers to the regional warehouses, obviating the need for the plastic cases and decreasing the distance that DVDs needed to be shipped. As noted earlier, the manufacturing energy cost of DVDs dominates the cost of shipping DVDs. This manufacturing energy cost could be decreased by increasing the durability and reusability of the DVD. If the reusability of a DVD could be doubled, the energy expended in shipping a DVD once could be reduced to 0.74 MJ. But even with this reduction we observe that energy-optimized streaming would still be 56% of shipping a DVD. It may also be possible to ship movies stored on greener reusable media such as USB flash disks, increasing the number of times the media can be used.

## 9. CONCLUSION

In this paper we have quantified the total energy consumed and the carbon footprint of two methods of movie content delivery traditional mailing of DVDs and online streaming. Our results have shown that when adopting data center and networking-related energy reduction techniques from the literature, consumption and the carbon footprint of streaming can be reduced to approximately 30% and 65% respectively of that of shipping making streaming delivery an attractive option. However, this advantage may not last if movie data rates continue to scale.

Reducing energy needs and the carbon footprint by approximately a factor of two is certainly a significant achievement energy is one of the major costs in running a data center, and any less CO2 emitted into the environment is for the better. However, our field is in many ways used to orders-of-magnitude and exponential increases in performance and utility, e.g., Moores Law, Metcalfes Law, and the concomitant increase in link transmission capacity (e.g., from 10 Mbps to 10 Gbps Ethernets in a short period of time). Filtered through this lens, a factor of two improvement in performance could be perceived as small. Perhaps it is the case that advances in energy-related aspects of content delivery systems (and green networking in general) will be slower, although hopefully just as steady. Indeed, this has been the case in other industries (e.g., the automotive) and our sense is that it has been historically true in the IT industry as well. It may also be the case that significant gains result primarily as a sum of gains in the many individual component technologies that comprise the system, e.g., as has arguably been the case with laptops, where advances in CPU technology and energy efficiency, disk drives, displays, solid state drives and battery technology have all contributed significantly.

As future work, we will study the cost-benefit tradeoff of such innovations to determine which techniques can reduce the energy footprint at the least cost.

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# 11. APPENDIX

## 11.1 Manufacturing Cost of Truck

| **Materials** | **Percentage** | **Energy Spent (Production - Recycling) (MJ/kg)** | **Total Energy consumed (MJ)** |
|---|---|---|---|
| Steel | 54.9 | 13 (65-52) | 64661.22 |
| Copper | 1.3 | 105 (140-35) | 12366.9 |
| Zinc | 0.5 | 104 (112 - 8) | 4711.2 |
| PowderMetal | 0.8 | 93(93) | 6740.64 |
| Rubber | 4.2 | 88 | 33485.76 |
| Fluids | 5.9 | 88 | 47039.52 |
| Plastics | 7.7 | 42 | 14650.02 |
| Aluminium | 5.8 | 135 | 35469.9 |
| Other | 3.1 | 88 | 24715.68 |
| Cast Iron | 12.8 | -37 | -42908.16 |
| Glass | 3.0 | n.a. | n.a. |
| Total | 100 | | 200932 |

**Table 7: Energy costs of Truck Raw Materials**

We estimate the manufacturing cost of a truck from that of a car, due to unavailability of data. The values in the first three columns of Table 7 are obtained from [40]. The total energy consumed for each component is calculated for a 20,000lb truck [29]. As percentages of wrought aluminium and cast aluminium are not given in [40], we consider equal quantities of both being used. We make a similar assumption for plastic. Moreover, since energy value of glass is not supplied, we do not include that in calculations.

## 11.2 Energy Consumption By Television

We calculate the energy spent in watching the movie on the LCD as well as the fraction of the manufacturing energy of the LCD which should be attributed to a single viewing of the movie. The power rating of a 36inch LCD television is 144W [4]. Hence the energy consumed by the LCD for watching a movie once is $144 * D = 1.0368MJ$.

Due to the unavailability of data for manufacturing a 36inch LCD television, we scale the manufacturing cost of a 15 inch LCD television [19] and estimate the manufacturing cost of a 36 inch LCD as 8294.4MJ. Therefore the cost of viewing a movie once is 4.403MJ. Hence the total energy cost of viewing a movie once on a LCD (including manufacturing) is 5.44MJ.

## 11.3 Energy Consumption By Laptop

From [30] we find that the total energy cost of manufacturing a laptop is 4031MJ. We assume that a laptop is used for 3 hours in a day [44]. Thus, the total energy of manufacturing that should be attributed to a single streaming of the movie is

$$\frac{4031 * D}{L * (3 * 3600)} * R = 2.14\text{MJ}$$

We consider the laptop to be IBM T400 (90W) [17]. The power consumed by a laptop for watching a movie is $90 * D = 0.648$MJ. Hence the total energy cost of viewing a movie once on a LCD (including manufacturing) is 2.788MJ.