Global Warming Largely Due to Urban Heat Islands with Humidity Forcing
A Feasibility Assessment

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Alec. Feinberg, DfRSoft

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Abstract

In this paper we provide a feasibility study to show that global warming could be largely due to Urban Heat Islands (UHI) with Humidity Forcing (HF) from Hydro-HotSpots (HHS). We denote hydro-hotspot as precipitation evaporation and bulk heating from low albedo manmade type roads and city surfaces, including cars and engine hoods. This includes both Highly Evaporating Surfaces (HES) and bulk warm waste Rain Water Management (RWM). Such Humidity Forcing (HF) root cause is then albedo forcing due to the creation of HHS. This leads to the conclusion that changing the albedo of cities and roads could be the strong solution to Global Warming (GW).

1. Introduction

Global warming is commonly illustrated with CO2 correlation to population growth and global warming trends. Similarly, one could argue that city growth is correlated to population growth which in-turn then would also be correlated to global warming if we have a feasible mechanism. Some authors have already shown that as much as a third of global warming is due to UHI [1,2] effect. This is related to albedo forcing. Along with this one could assert, that city and road growth provides what we term Hydro-HotSpot (HHS) creation. City and road albedo forcing produce UHI high temperatures when in combination with precipitation create Highly Evaporating Surfaces (HES). Such surface as illustrated here are capable of reducing local relative humidity while increasing specific humidity. This combination would then also be correlated to global warming trends. Humidity forcing potential while hard to exactly quantify, is then certainly a possible contributor to global warming. One of the CO2 arguments treats the observed specific humidity increase and relative humidity decrease as due to a warming feedback mechanism from CO2 causing ocean evaporation and ignores the possibility of human humidity forcing [3,4]. Once HF feasibility arguments are made from HHS caused by UHI, it diminishes the CO2 argument. We proceed under this contention with simple feasibility assessments and the goal to spur strong interest in this area.

1. Highly Evaporation Surface and Rain Water Management Feedback

The effect of UHI and road Hydro-HotSpots (HHS) from Highly Evaporating Surfaces (HES) global warming feedback is illustrated in Figure 1.

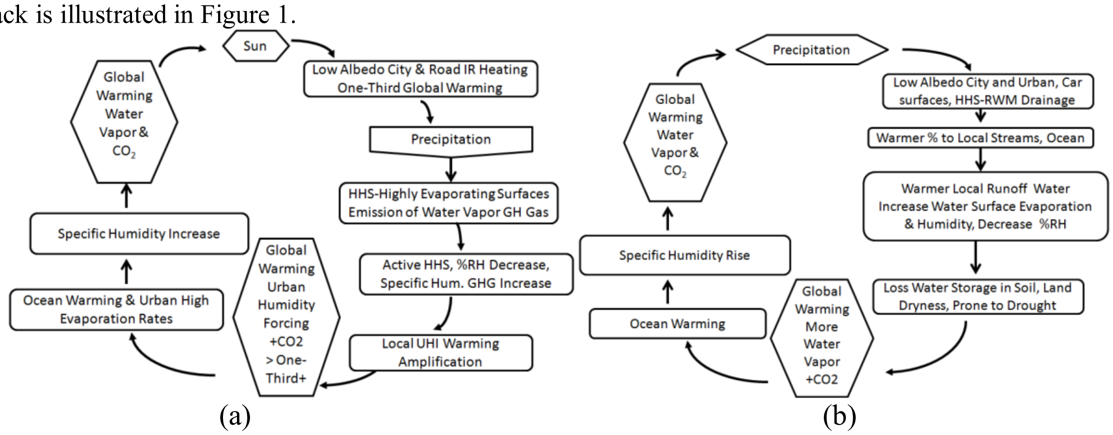

Figure 1 a) HHS- HES feedback view of contribution to global warming, b) HHS Rainwater Management (RWM) high temperature water cycling in Climate Change

Figure 1a shows HHS-HES feedback that may be summarized:

- Low albedo cities and roads emitting infrared radiation (IR), increased warming (approx. 1/3)
- Precipitation occurs, followed by evaporation of HHS-HES moisture, lower %RH increase specific humidity GreenHouse gas in warmed city area
- Local heat amplification, less local cooling with increased specific humidity amplifies heat index
- Local warming radiates heat increasing Global warming more than 1/3 original estimate
- Evaporation increases in cities and ocean primarily from UHI and roads creates lower %RH and higher specific humidity globally along with CO_2 increase more evaporation
- More greenhouse gas in the form of moisture and eventual further warming.

Figure 1b Shows HHS-RWM feedback that may be summarized:

- Higher temperature storm water is collected off of HHS buildings, streets and hot cars

- A large percentage is drained to nearby rivers, lakes or ocean
- Warmer air allows for increase in specific humidity
- The impermeable city building and roads have replaced vegetative land creating lost area that would have stored cooler water in soil keeping the land moist with less generated heat.
- This increases land dryness can mean less land evaporation and more ocean rain.
- The RWM is often warmer from HHS activity raising storm water temperatures from hot city buildings and street cycling each year billions of gallons of rainwater to local streams, lakes and ocean contributing to local surface water temperature increases depending on location. These runoffs affect atmospheric warming trends and GH gases
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2.0 Albedo Forcing - One-Third of Global Warming Feasibility Estimates and Corrective Actions

There have been numerous studies on Urban Heat Island (UHI) effects. We focus only on a few publications that found significance in UHI contribution to global warming. McKitrick and Michaels [5] found that half of global warming trend from 1979 to 2002 is caused by UHI. Research in China [1,2] indicates that UHI effects contributes to climate warming by about 30%. There is an apparent push-back with little effort to date on changing city albedo forcing, as the focus is mainly on CO_2.

A simplistic feasibility model has its strength in

- Supporting estimate from other authors [1,2,5]
- Corrective action assessment using “what if” scenarios for changes to the albedo

Table 1, obtained from Appendix A, illustrates UHI albedo forcing GW feasibility. The simple albedo model supports the contention that cities and roads heat increase can be as much as one-third, in agreement with these few studies [1,2,5]. The table also provides (last row), a corrective action “what if” scenario for albedo increase to 0.5.

Table 1 Appendix F Results of GW Temperature Budget Change With City Surface Areas and Albedos

and Year	Solar Surface Area of Cities Appendix A	Albedo Roads	Albedo Cities	Global Albedo	Temperature*	UHI Radiative Forcing**
IPCC	0.046	0.04	.12	28.92	0.33 ^oF	0.14 W/m^2
1950	1.20%	0.04	0.12	29%	0.2^oF	3.46W/m^2
2019	2.95%	0.04	0.12	28.72	0.65^oF	8.45 W/m^2
2019	2.95%	0.5	0.5	29.45	-0.53^oF	4.9 W/m^2

*where Temp is given by: P_{Total}= 1361W/m2 {0.25 x 1-Albedo} =σT^4, **Sec 3

We note that global albedo changes might be hard to measure from satellites due to cloud coverage, but are undeniable decreasing with increasing cities and roads. City urban areas are not well known and certainly, the solar heating surface area is even more complex to estimate. Although the models in Appendix A on city surface estimate are crude, they demonstrate estimates to further support the cited authors [1,2,5]. From this feasibility we find:

- Actual shift from 1950 may be 0.5^oF (0.7-0.2) due to Cities & Road increases, which is 33% responsible for global warming in agreement with the quoted authors [1,2,5].
- A “what if” corrective action results show if we can change city albedos to 0.5 and roads, total shift is 1.3^oF ={0.7-(-0.5)}. This almost equates to the observed global warming.

3.0 Percent of Global Warming Due to Greenhouse Gases and Albedo

Under the contention of humidity forcing occurs mainly from cities and roads, we provide feasibility estimates shown in Table 2 of forcing contributions due to Albedo, CO_2, and water vapor increases (ignoring other GH gases) from 1950 to 2019.

Table 2 Calculated Forced Effects Causing Global Warming from 1950 to 2019

Forced Effect	Contributing Change	Temperature Increase	Percentage
Albedo (Cities & Roads)	0.29 to 0.287	0.5^oF	33.33%
Water Vapor	225.6-243.9 PPM increase	0.89-0.96^oF	61.03-65.26%
CO_2	9-27.4 PPM increase	0.036-0.11^oF	1.41-4.23%
Greenhouse Gas Increase	1%=60.3%-59.3	(~1^oF, $H_2O + CO_2$)	
Totals	430PPM	1.5^oF	100%

Table 2 estimates are made as follows:

In Table 2 we concluded the change from 1950 to 2019 due to albedo forcing was 0.5°F . We next note that the Earth's energy budget is 241.58 Watts/m^2 (where P_{Total}= 1361W/m2 {0.25 x (1-0.29)}). In 1950 the average temperature was 57°F. This yields 384.93 Watts/m^2 ($P=\sigma T^4$). This leaves 143.3Watts/m^2 of power emitted back by GH gases which is 59.34% of the 241.58 Watts/m^2. In 2019 Earth energy budget is 242.63 (P_{Total}= 1361W/m2 {0.25 x (1-0.2869)}, see Table 2), the average temperature is taken as 58.5°F yielding 389 Watts/m^2 which leaves 146.36 Watts/m^2 above the Earth's energy budget or 60.3% emitted back by GreenHouse (GH) gases. The difference of the emitted back radiation is 3.1 Watts/m^2 (note we took into account an albedo change in 2019 in the Earth's energy budget that makes this estimate lower than the 4.1 Watts/m^2 typically found) and the difference in the percent of emitted back Greenhouse gases is

$$1\%=143.3/241.58-146.36/242.63=60.3\%-59.3\% \quad (1)$$

Therefore, this must be the percent of GH gases required to increase global temperatures 1.0°F. Using the approximate 300 PPM value for CO_2 in 1950 and an average estimate of 25,000 PPM for water vapor in our atmosphere [5, 6], the 1% GH gas increase is estimated to be

$$25{,}300\text{PPM x } 1\%=253\text{PPM} \quad (2)$$

increase in 2019. In 2019 the estimate increase in CO_2 is 114PPM (currently 414PPM). The typical contribution of blackbody spectrum absorption for CO_2 is 8%-24% leaving 76-92% for water vapor (where we are ignoring other GH gases) [5,6]. It is actually difficult to predict such percent GH gas contribution and we are using values from other authors [5,6]. Using the low 8% value first for CO_2 and the 253 PPM we must have

$$243.9\text{PPM } (H2O\uparrow) + 114\text{PPMx}8\% \ (CO_2\uparrow)=253\text{PPM} \quad (3)$$

The effect of water vapor and CO_2 vary depending on a clear day or cloudy day with precipitation. Dividing the LHS by 430 PPM yields the fractional GH of 1°F temperature contribution (1.5°F rise from 1950 with 0.5°F due to albedo). The full temperature sum is then

$$0.96^oF\ (H_2O\uparrow) + 0.036^oF\ (CO_2\uparrow) + 0.5^oF\ (\text{Albedo})=1.5^oF\ (\text{from 1950 to 2019}) \quad (4)$$

Since CO_2 can vary in it absorption strength, we consider higher values by a factor of 3 in its GH effect [5,6], this upper value yields the range in estimates to global warming contributions shown in Table 2.

We note the usual argument of CO_2 control in the upper atmosphere is diminished [3,4]. That is, such arguments treat water vapor as a feedback rather than a forcing mechanism. Here, increased warming from albedo forcing feeding humidity forcing from HHS in the presence of precipitation would lessen the CO_2 mechanism conjectured by some climatologist [3,4].

- *In this view, feasibility indicates that the albedo of cities & roads is a strong corrective action for global warming.*

4.0 Evaporation Rate of Cities Vs. Ocean Feedback

In this feasibility assessment, Equation 1 and 2 are important as they indicate the increase in PPM of GH gases. One could argue that the increase in humidity from 1950 to 2019 is due primarily to the GW ocean feedback mechanism and perhaps some contribution due to HHS. Here we illustrate feasibility that helps to show that humidity forcing from HHS in cities likely plays a strong role in GW as well.

In this example, the evaporation rate increase of HHS simulated area in Cities (Ec) vs that of the Ocean (Eo), we make comparison between 1950 and 2019 relative to a possible average hydro-hotspot of 50°C (using average range from 25°-75°C) for simulated area growth via the final ratio. We show that the evaporation rate increase is dominated more by city area growth rather than ocean temperature change. In this assessment, we will first ignore the evaporation wind effect. The comparisons for the effects are:

$$HHS_{effect-o}(1950) = \frac{E_O}{E_C} = \frac{A_O}{A_C} R(T_O, T_{HHS}) \frac{E_{WO}}{E_{WC}} \frac{RH_C}{RH_O} = 40.8x\frac{1}{6.69}x100x0.5 = 304.9 \quad (5)$$

and

$$HHS_{effect-o}(2019) = \frac{E_O}{E_C} = \frac{A_O}{A_C} R(T_O, T_{HHS}) \frac{E_{WO}}{E_{WC}} \frac{RH_C}{RH_O} = 16.3x\frac{1}{6.28}x100x0.5 = 129.8 \quad (6)$$

where E_O,E_C=Evaporation Rate of Ocean, Evaporation Rate of Cities
AO, AC= Surface Area of Ocean, simulated proportional Area of City Surfaces growth rate (Ao/AC=49%/3%=16.3 in 2019, Ao/AC=49%/1.2%=40.8 in 1950)
R(T_O=16C,T_{HHS}=50C,1950) Temp. rate factor Ocean to City HHS ~6.69
R(T_O=17C,T_{HHS}=50C,2019) Temp. rate factor Ocean to City HHS ~6.28
$where\ R=\exp\{\frac{E_a}{K_B}(\frac{1}{T_{HHS}}-\frac{1}{T_O})\}$, Ea=0.45eV [33]
E_{WO}, E_{WC}= Percent of time surface exposed to water, E_{WO}=100%, E_{wc}=1% ~100
RH_C, RH_O=Local relative humidity of ocean and RH of city near surface ~40/80

From Eq. 5 and 6 we find the percent increase in evaporation rate from HHS relative to the ocean since 1950 (ignoring wind) as

$$\%2019\,Increase=\frac{304.9-129.8}{304.9}=57.4\% \qquad (7)$$

We now look at the wind effect. We will consider that the ocean wind evaporation factor has not changed much from 1950 to 2019. However, city growth increases friction near the ground level so the wind evaporation effect factor is diminished in cities by comparison to the ocean from 1950 compared to 2019. Then the results in Eq. 7 is now modified by this factor

$$57.4\%x\frac{W_{O/C}(1950)}{W_{O/C}(2019)}=57.4\%x\frac{W_C(1950)}{W_C(2019)}=57.4\%xf_W \qquad (8)$$

where f_W is an unknown factor between 0 and 1. If we take f_W as a median value of 0.5, for a rough wind reduction estimate in cities, this would yield a 29% growth rate in evaporation compared to the ocean effect.

In summary, humidity forcing from HHS shows a strong evaporation growth rate compared to ocean changes in evaporation rate from 1950 to 2019. Given that UHI may be the original heating source, then warmer air is likely to get mor contributions from HHS compared to oceans. This supports reasonable strong feasibility that the 1% increase in moisture greenhouse gas can have high contributions from an urban humidity forcing/feedback effect.

5.0 City & Asphalt Hydro-Hotspot Lowering of the Local Relative Humidity Example

If the ambient temperature when it rains is 25^oC/98%RH and the HHS surface temperature is 60^oC (1000Watt/m^2), then the local relative humidity at the hotspot surface is reduced from 98%RH to 15.6%RH.

This is shown in Appendix [C]. Such cumulative effect from buildings and streets in a city likely will lower city's equilibrium relative humidity compared to nearby rural areas. This cumulative effect is likely over the years related to the ~4.1 Watts/m^2 change seen in global warming. The sharp change in lowering relative humidity is in contrast to a more mild ocean feedback. However, evaporation from ocean with its large area effect is likely to also provide strong feedback as as has been suggested by climatologist. The correlation to lowering relative humidity and global warming is well established [7,8]. Feasibility suggest that ocean feedback is important, but the root cause of UHI with humidity forcing can play the catalyst for GW in general.

5.1 GW Reversibility

One might think that the relative humidity would eventually go back to the original equilibrium state, and for the most part it almost does. However, data unfortunately shows that global relative humidity equilibrium is decreasing [7,8] and this must be correlated to the 4.1 Watts/m^2 GW increase (Sec. 3). This same energy is then needed to reverse this change. However, the concept that it is strongly due to UHI with humidity forcing and ocean feedback, shows that if humidity dominates the GW tendency, it would be more reversible in comparison to CO2 issues. Making changes to the albedo root cause is certainly a non trivial corrective action for cities, but has this very positive potential outcome. On the other hand, approximately 22% of ice and snow is at risk (Table B1) to add to a decreasing Earth albedo feedback effect in GW thermal runaway. This creates the need for this type of urgent corrective action.

6.0 Rain Water Management

Associated with city issues and humidity increase is Rain Water Management (RWM). Impermeable city surface create problems with RWM runoffs. The fact that this bulk water is warm and eventually cools as it evaporates is part of the issue from HHS. Another issue somewhat seemingly unrelated is the loss of wetlands, but correlates to an increase evaporation rate. Sometimes, rain follows local evapotranspiration. Apart from precipitation, evapotranspiration is the major component in the hydrologic budget. If water is runoff far from the source and there is severe loss of wetland, then the area can be prone to increased dry days and possible draught [15,16]. Many cities dump their runoffs in the ocean and this does not help the situations [17,18].

7.0 HHS-HES and HHS-RWM Reduction Suggested Solutions

Global warming solutions can only occur if root causes are addressed. In this assessment, the root cause is primarily related to albedo issues in cities along with evaporation problems. There is strong interest in albedo changes in cities already due to the UHI effect. Identifying a stronger correlation to GW would perhaps provide strong motivation for critical immediate measures. The following are suggested corrective actions:

- Further studies are required on Humidity Forcing to understand the contribution to GW
- Change Albedo of roads and cities will reducing HHS and the area effect dramatically, i.e. paint roads and building with reflective colors (minimally higher than albedo of 0.5)
- Engineering roads to be more HHS eco-friendly
- Reduce driving speeds during rain to reduce evaporation rates can also reduce KE molecules
- Change to electric cars with HHS - cooler hoods
- Paint all cars metallic or white (high reflective colors)
- Move car engines to the back of the car with as little rain surface area as possible
- Improve HHS-HES irrigation to soil
- Improve vegetation in run off areas by planting millions of trees in HHS-HES areas
- Require negative population growth to reduce increase HHS-HES surfaces
- Adopt Low Impact Development (LID) in city planning and improvements for design approach aiming to mimic naturalized water balances
- Cool rain water runoff with green electricity prior to dumping it in the ocean
- Severe HHS-RWM changes are required to stop runoff into the ocean worldwide

Appendix A Solar City Surface Area Estimates:

One of the main criteria needed for UHI albedo modeling are estimates of solar surface areas covered by cities and roads. The effect of area increase by a factor of about 3 in 2019 Column 2 compared to 6 in Table A1 is somewhat supported by Decheng et al. [19] that found UHI changes the climate in area 2–4 times larger than its own area. We have used an average factor of 3. Certainly, estimating solar city areas of cities globally from 1950 to 2019 is an impossible task. Therefore, we use this estimate of Decheng et al [19] and illustrate how this estimate could be justified.

To further justify the rough facto of 3, we use a 2010, estimates from a GRUMP [9] study and its critics [10] of the study find it is somewhere between 2.7% and 0.85%. We will take a round number of 1% coverage of the Earth in 2010. The growth rate of cities is taken from the U.S. Census of 0.8% per year [11]. We are interested in Global Warming trends from 1950 to 2019. The extrapolation using this growth rate is shown in Column 2 of Table 1. We then need to make some rough estimate that buildings occupied 50 % of the urban land (Column 3). Finally we add a multiplication factor assume each building sides equates to 7 times the bottom surface area in 1950 and as buildings have become taller [12] about 10 times in 2019 (Column 4). The estimates are shown in Table 1 for example the 1950 estimate is 0.62x0.5+0.62x.5x7=2.48 (column 5) and then we take 50% illumination factor (Column 6).

Table A1 Values used to estimate the Solar Surface area in cities

Year	Urban Area Percent	Buildings % Coverage	Surface area & Height factor	Solar surface Area %	50% Illumination
1950	0.62	0.50	7	2.48	1.2
2019	1.10	0.50	10	6.05	3.0

Below we provide a simplified albedo model and illustrates the Earth's energy budget between 1950 and 2019 taking into account these effective solar surface areas.

Appendix B Simplified Weighted Albedo Model 1950 & 2020

Below is a simplified Albedo model to estimate the Earth's total albedo decrease with increase in city and road areas and a decrease in grass lands.

Table B1: Albedo=0.29 [13], 1950

Surface	Enter % of Earth Area	Enter Albedo (0-1)	Weighted Albedo % Results
Water	71		
Snow	12	0.8	2.40
Ice	10	0.6	4.00
Open Ocean	49	0.06	46.06
Land	29.1		
Roads (0.04)	0.8	0.04	0.77
Urban Cov (0.12)	1.2	0.12	1.06
Forest (0.17)	8.6	0.17	7.14
Grass lands (0.26)	8.6	0.26	6.36
Desert (0.4)	9.9	0.4	5.94
Sum % of Earth Area	100.1		
Weighted Earth			26.27
Clouds (0.47)	60	0.472	31.68
			Global Weighted Albedo in
Global=Average(Clouds & Weighted Earth) %			28.98
Global=Average(Clouds & Weighted Earth)			0.2898

Table B2: Albedo=0.287, 2019

Surface	Enter % of Earth Area	Enter Albedo (0-1)	Weighted Albedo % Results
Water	69.45		
Snow	11.39	0.8	2.28
Ice	9.63	0.6	3.85
Open Ocean	48.43	0.06	45.52
Land	30.54		
Roads (0.04)	0.78	0.04	0.75
Urban Cov (0.12)	2.95	0.12	2.60
Forest (0.17)	8.45	0.17	7.01
Grass lands (0.26)	8.64	0.26	6.39
Desert (0.4)	9.72	0.4	5.83
Sum % of Earth Area	99.99		
Weighted Earth			25.76
Clouds (0.47)	60	0.472	31.68
			Global Weighted Albedo in
Global=Average(Clouds & Weighted Earth) %			28.72
Global=Average(Clouds & Weighted Earth)			0.2872

Table B3: Albedo=0.294, "what if"

Surface	Enter % of Earth Area	Enter Albedo (0-1)	Weighted Albedo % Results
Water	69.45		
Snow	11.39	0.8	2.28
Ice	9.63	0.6	3.85
Open Ocean	48.43	0.06	45.52
Land	30.54		
Roads (0.04)	0.78	0.5	0.39
Urban Cov (0.12)	2.95	0.5	1.48
Forest (0.17)	8.45	0.17	7.01
Grass lands (0.26)	8.64	0.26	6.39
Desert (0.4)	9.72	0.4	5.83
Sum % of Earth Area	99.99		
Weighted Earth			27.24
Clouds (0.47)	60	0.472	31.68
			Global Weighted Albedo in
Global=Average(Clouds & Weighted Earth) %			29.46
Global=Average(Clouds & Weighted Earth)			0.2946

Results of the simplified weighted model are exemplified in Table B1 for 1950 with the full estimates provided in Table 1. Equation B1 is the weighted albedo by area, B2 is the weighted albedo with clouds.

$$Earth\ Weighted\ \ Albedo = \sum_i \{\%\,Earth\ Area_i\ x\,(1 - Surface\,Item\ Albedo_i)\} \quad \text{(B1)}$$

Equation B2 is the average weighted albedo with clouds.

$$Global\,Weighted\ Albedo = Average\{((1 - Clouds\ Albedo)\,x\,\%\ Coverage) + (1 - Earth\ Weighted\ Albedo)\} \quad \text{(B2)}$$

Appendix C: Example of Hotspot Local Relative Humidity in Cities and Streets

The following equations were used for this estimate in Section 4 [14] regarding the HHS local %RH of 15.6%:

$$HHS_{\ RH} = RHamb\,\frac{P_{sat}(T_{amb})}{P_{sat}(T_{HHS})} \quad \text{(C1)}$$

Here HHS_{RH} is the hydro-hotspot's local %RH, RH_{amb} is the ambient %RH, and P_{sat} is in KiloPascals defined as

$$P_{sat}(T) = e^{(a + \frac{b}{T} + \frac{c}{T^2} + \frac{d}{T^3})} \quad \text{(C2)}$$

Where a=16.033225, b=-3515.138, c=-290850.583, d=5097236.05, and T=Temperature in ^{o}K. Psat can also be obtained from standard tables.

Biography: Alec Feinberg is the founder of DfRSoft. He has a Ph.D. in Physics and is the principal author of the books, Design for Reliability and Thermodynamic Degradation Science: Physics of Failure, Accelerated Testing, Fatigue, and Reliability Applications. Alec has presented numerous technical papers and won the 2003 RAMS best tutorial award for the topic, "Thermodynamic Reliability Engineering."

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