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BEST PRACTICE
AMP WORKING GROUP

Case Study

Energy Efficiency Initiatives

Auckland Transport

Street Lighting

Initiative number 2013_03

December 2013

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Executive Summary

A number of benefits can be obtained through innovative street lighting products being made available in the market and through smart energy purchasing arrangements.

Energy efficient LED lighting and bulk purchasing of energy are two initiatives that will provide immediate benefits in a street lighting network.

LED lighting can be used to replace existing HPS lighting at a lower wattage rating. This will provide a reduction in power consumption and a saving in power costs.

Economy of scale can also play a significant part in negotiating lower power rates with energy companies and hence bulk purchasing through joint ventures is worth serious consideration.

Key findings from this Streetlighting case study are:

1. Replacing existing 70W HPS luminaires on local roads with 38W LED luminaires provides same (or better) levels of service and will lower the power consumption rates and power costs
2. Bulk purchasing of power through a single contract for multiple areas will provide efficiencies due to "economy of scale"
3. Selecting LED suppliers will need to be done through a robust "pre-qualification" process
4. Establishing a Central Management System that enables dimming and constant light outputs will provide significant savings for a large streetlight network

A number of key points to be noted are highlighted below:

Feasibility Study for LED

Network specific feasibility studies will need to be carried out to establish the economic and technical viability and to select the best option for energy savings as a range of factors can influence the final decision.

Some key factors to be considered are: size of the network, initial costs, priority of the organisation, investment periods and technical issues in relation to the replacement of HPS with LED.

Pre-qualification of LED suppliers

A rigorous process for pre-qualification of suppliers for the supply of LED luminaires will be necessary. The factors that need to be considered for pre-qualification include:

- Track record of the performance of LED luminaires (Based on experience from similar installations worldwide)
- Track record of the supplier

- Physical presence of the supplier in NZ
- Level of Guarantees

Further details of the pre-qualified suppliers and the process adopted by Auckland Transport may be obtained by contacting;

David Dick	Auckland Transport	David.Dick@aucklandtransport.govt.nz Phone: 09 447 4406

Background to procurement decisions and economic analysis

A detailed technical assessment completed for Auckland Transport is included with this report providing more details of this case study.

Recommendations

Based on the findings of this case study the following recommendations are made for the consideration of Road Controlling Authorities in order to reduce power consumption rates and energy costs:

1. Consider replacing existing HPS luminaires with suitable LED luminaires
2. Adopt bulk power purchasing practices
3. Implement a robust system for selection of LED suppliers

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1 Introduction

1.1 Project Outline

Project Name:	Energy Efficiency Initiatives – Auckland Transport
Project Location:	Auckland Region
Project Objectives:	Energy efficiency in Streetlighting
Length:	Auckland Transport road network 7,200 km
Traffic Volume:	N/A
Supplier(s):	External
Project Stage:	Scope completed and approved for implementation
Value: (cost savings)	Net cost savings between $32.4M and $ 35.7M expected over 20 years
Scope of Work:	Replacement of 40,000 existing high pressure sodium luminaires with appropriate LED luminaires over a period of 4 years and implementation of a web based Central Management System
Environment:	N/A
Constraints:	Time & Resources
Project commenced:	To be implemented over 4 years beginning 1 July 2014
Key Issues:	Energy usage, Energy costs, Levels of Service

1.2 Project Team

Name	Organisation / Role	Contact Details (Email and Telephone)
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2 Case study

2.1 Introduction

Managing Auckland region's Road and PT networks, except State Highway network, is the responsibility of Auckland transport (AT).

AT owns 100,000 street lights on the network which accounts for 72% of the energy costs of the organisation.

A recent review carried out by AT investigated a number of options to achieve more energy efficient network for streetlights.

This review has focused on Category P roads (pedestrian predominant) which comprise approximately 60% of AT's lighting network, in particular residential streets.

Category V roads (vehicle predominant) are excluded from this review on the basis that currently the new technologies for higher wattage luminaires is more expensive and the logistics of changing these luminaires involves costly traffic management.

Furthermore, this is a one for one replacement of existing HPS luminaires and does not address installing additional luminaires to eliminate dark spots (in-fill lighting) to comply with the AS/NZS 1158 standard adopted by AT. Such in-fill lighting requires on-going capital funding provided through the AMP and LTP.

This initiative falls within a program of work to align AT's energy consumption with Levels of Service requirements and by so doing eliminate waste and gain better control over load. Load management provides the opportunity to reduce energy consumption when normal levels of lighting are not required.

2.2 What is proposed?

AT is implementing two specific proposals to achieve more energy efficiency gains from the Streetlighting network.

1. Replace 40,000 HPS luminaires with LED luminaires beginning July 2014 and that the programme be completed over a four year period.

2. Install a Central Management System (CMS) on the 40,000 LED luminaires being retrofitted above and to eventually roll it out across the remaining network.

2.3 What are the main benefits?

The benefits of this approach are:

- The current cost of energy for the street light network is $13M per year. By upgrading the luminaires to more efficient luminaires and the installation of a CMS will result in net savings between $32.4M to $35.7M over a 20 year period.
- A 50% reduction in energy use

- Reduced maintenance due to more reliable luminaires and longer lamp life. Note: Current HPS lamps are changed every 5 years whereas the design life of a LED is 20 years with an expected life of up to 25 years.

- The LED's have a white light which is internationally recognised as providing a safer environment for pedestrians and vehicles.

2.4 Alignment with Auckland Transport Strategic Context

This proposal to retrofit CMS controlled LED luminaires in place of the existing HPS luminaires supports three of the four outcomes of AT's integrated Transport Programme:

1. Operate, maintain and renew infrastructure optimally
   Installation of LED luminaries and CMS will operate the Streetlighting network in an optimum manner by reducing energy usage and realising cost savings

2. Invest in new infrastructure, services and technology
   Whole programme is centred on new technology available in LED and ICT

3. Sustainability

2.5 What are the other advantages?

While there are commercial benefits attached to migrating away from HPS lamps in respect of lower energy consumption and maintenance costs, the latter due to lamp longevity, there are qualitative factors that also support this initiative including:

- Improved road safety
  International research shows light quality affects road safety and between 30-65% of night time accidents can be attributed to the quality of white versus yellow light and the flow on effect with reaction time. In New Zealand 33% of traffic accidents occur in relative darkness at an estimated cost of $1.2 billion. The human cost and flow on financial impact is therefore significant in its own right.

- Mature technology
  The lighting technologies under consideration are mature and low risk with international implementations achieving crystallised savings and enhanced street lighting performance. Significant technology developments are occurring out of Europe and USA in particular. The current approved luminaires for use on the AT network are manufactured in either Europe or the USA.

- An improved and safer urban landscape with less spill light and road surface glare.

- A growing awareness of the environment and sustainable business practices. AT has demonstrated its commitment to reducing its carbon footprint.

2.6 What else is needed to gain the maximum benefit from this proposal?

The installation of a Central Management System (CMS) with the LED luminaires is essential to maximise the benefits of the new system.

This will enable each light to be controlled and monitored through the CMS. At present lights are switched by a relay or photocell on the supply end of dedicated circuits or individual photocells in each luminaire. The new system is much more reliable and means in the event of a failure that only one light is out.

AT already have a CMS system established at Eden Park that has been recognised by awards for innovation and excellence.

A CMS will:

- Switch the lights on and off
- Control the level of light during the night saving energy
- Monitor each light and report any malfunction
- Measure the energy used at each light which is much more accurate for energy purchase

The advantages of the system are:

- Enhanced customer service.
- Adjust light levels to match traffic and weather conditions.
- Dim light levels at night resulting in energy saving.
- Constant light output over the lamp life saving energy and extending the lamp life.
- Design the exact light levels required by trimming the light output rather than choosing the next highest standard lamp size.

- Enhanced driver/pedestrian safety through instant fault reporting and improved response to outages.
- Better forecasting and planning through up to date network information feedback.

Currently, street lighting is unmetered supply meaning that energy charges are calculated on the rated power of each luminaire connected to the network times hours of operation (burn time).

The migration to lower wattage luminaires will therefore result in an immediate reduction (each month) of energy and cost savings.

AT is working with the energy suppliers to have energy calculated using either variable dimming profiles or metered energy quantities relayed back through the CMS. This work is well advanced and is now in the stage of installing check meters in the field to verify the measured/calculated quantities of energy used.

We have investigated the financial benefits of capturing carbon credits through the introduction of lower energy usage installing LED lights and the CMS. We have determined the value is not significant as an input to the financial model and therefore has been excluded.

2.7 Implementation

The procurement of two Streetlighting maintenance contracts to serve the Auckland region is currently underway and the scope of these contract will include the installation of 40,000 new LED luminaires on local streets over a period of 4 years. The programme is planned to commence at the beginning 1 July 2014.

The Procurement of a suitable CMS system is also underway at present.

3 Recommendations

Specific Recommendations	Suggested Action to be Taken
▪ Identify suitable Streetlighting networks to implement LED retrofit programmes	RCA's may consider similar approach to Auckland Transport to implement energy efficient street lighting
▪ One on one replacement can provide immediate energy savings due to low wattage luminaires	
▪ Implementing a suitable Central Management System can provide significant benefits	

4 Appendix

Further to the discussion of this paper at the REG AMP meeting held on 16th August 2013 a number of Issues have been raised and following is a summary of these issues with clarifications where possible for further consideration.

1. **Overall lighting decision required and not just LED Installation**

A number of potential options have been considered by AT for energy savings in the network and the two schemes being proposed will provide the maximum benefits. These two schemes are:

Scheme 1 – Replacement of HPS with White Light Luminaires on Category P Roads
40% of the existing network consists of 70W luminaires with High Pressure Sodium (HPS) lamps. It was proposed that these luminaires could be replaced with any combination of the following three lower output, white light options: 45W Cosmopolis, 50W Ceramic Metal Halide (CMH), or LED luminaires (typically 20/30 LED count). This scheme is feasible because the decrease in light output from 70W HPS to the lower outputs of the white light sources is offset by an increase in light quality (the eye is more perceptive to white light than yellow light).

Scheme 2 – Dimming and Constant Light Output
Installing a Central Management System (CMS) enables a number of cost saving maintenance efficiencies to be realised, including part-night dimming and Constant Light Output (CLO). Dimming reduces the light output during low traffic periods (eg. midnight to6am) to the next category light level of the Standard. A reduction in light levels of 50% is barely perceptible to the human eye. CLO enables energy savings by limiting the excessive light output of luminaires in their early life.

2. **Pre-qualification of LED suppliers**

AT is in the process of implementing a rigorous criterion for pre-qualification of suppliers for the supply of LED luminaires on an annual basis. The factors that will be considered for pre-qualification include:

- Track record of the performance of LED luminaires (Based on experience from similar installations worldwide)
- Track record of the supplier
- Physical presence of the supplier in NZ
- Level of Guarantees

3. Bulk purchasing with neighbours

AT's street lighting network is one of the largest in NZ and it has the advantage of "economy of scale" when negotiating for power supply. Bulk purchasing will provide advantages and Road Controlling Authorities may want to consider this approach by having agreements with adjoining organisations.

4. Relative size of network LED change

Network specific feasibility studies will need to be carried out to establish the best option for energy savings as a range of factors can influence the final decision.

5. Background to procurement decisions and economic analysis

Include to this report is the detailed technical report completed by AT's consultant OPUS which provides background information on procurement decisions and economic analysis of options that have been considered.

AUCKLAND TRANSPORT

Street Lighting Energy Strategy – Detailed Report

For Long Term Cost & Energy Savings

March 2012

OPUS INTERNATIONAL CONSULTANTS LTD

Street Lighting Energy Strategy – Detailed Report

For Long Term Cost & Energy Savings

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Contents

1 Executive Summary

This report identifies ways in which up to **$38M** (depending on the scale and timing of capital investment) can be saved in whole of life costs for street lighting across the Auckland Transport network. This can be achieved by the adoption of advanced lighting technologies which are now technologically mature and low risk.

This report follows a previous High Level Report identifying cost savings attainable through two power and maintenance saving schemes:
Scheme 1: the replacement of 70W HPS street lighting luminaires with lower power white light sources, and
Scheme 2: the establishment of a Central Management System, enabling dimming and Constant Light Output technologies and savings.

Recommendations

- We recommend that Auckland Transport implement the LED 5 Year Phase-In case assessed in this report, ie. the replacement of 40,000 70W HPS luminaires with the proposed LED luminaire on P3 and P4 Category roads, progressing the investment across Greater Auckland in a geographical fashion, 20% of the network per year.
- We recommend that a detailed Work Plan be commissioned to govern implementation of the above recommendation.
- We recommend that rollout of a Central Management System in tandem with the above scheme be considered.

2 Glossary

AT-HALL	Auckland Transport HID Approved Luminaire List – a schedule of HID luminaires which have been objectively assessed and approved for use in Auckland Transport commissioned designs
AT-LALL	Auckland Transport LED Approved Luminaire List – a schedule of LED luminaires which have been objectively assessed and approved for use in Auckland Transport commissioned designs
BAU	Business As Usual – reflects costs of existing maintenance practices on Auckland Transport's street lighting network
CLO	Constant Light Output – a means of reducing excessive light output over the early years of a lamp's life
CMH	Ceramic Metal Halide – the "new" generation of HID metal halide lamps, generates white light
CMS	Central Management System – a communications system that links assets, issuing control instructions and receiving feedback from street lights on the network
CPO	Philips Cosmopolis lamp – long life high output CMH lamp
HID	High Intensity Discharge – a mature lamp technology which generates light through striking an electric arc through a blend of noble gases
HPS	High Pressure Sodium – a type of HID lamp where the gas type is sodium based, generates dull yellow light
LED	Light Emitting Diode – an electronic technology which generates light through passing current through a semiconductor device
LTP	Light Technical Parameter – technical parameters that a lighting scheme must meet to be compliant with a certain Lighting Category/Standard
P3 (NZ)	Pedestrian Area Lighting Category 3 (NZ) – a mid-level lighting category for roads where lighting needs of pedestrians are dominant, specific to New Zealand
P3R	Pedestrian Area Lighting Category 3R – a mid-level lighting category for roads where lighting needs of pedestrians are dominant and where lighting arms are mounted on existing power poles
P4	Pedestrian Area Lighting Category 4 – a low-level lighting category

	for roads where lighting needs of pedestrians are dominant
P4R	Pedestrian Area Lighting Category 4R – a low-level lighting category for roads where lighting needs of pedestrians are dominant and where lighting arms are mounted on existing power poles
RAMM	Road Asset and Maintenance Management – a suite of software database applications Auckland Transport uses to maintain and manage Road Inventory and Condition data

3 Background

A previous report ("Street Lighting Energy Strategy – High Level Discussion Paper", February 2012) was commissioned by Auckland Transport to investigate energy savings through reduction of load on the Auckland Transport street lighting network. That research identified two recommended schemes for significant reduction of load on Auckland Transport's street lighting network.

Scheme 1 – Replacement of HPS with White Light Luminaires on Category P Roads
40% of the existing network consists of 70W luminaires with High Pressure Sodium (HPS) lamps. It was proposed that these luminaires could be replaced with any combination of the following three lower output, white light options: 45W Cosmopolis, 50W Ceramic Metal Halide (CMH), or LED luminaires (typically 20/30 LED count). This scheme is feasible because the decrease in light output from 70W HPS to the lower outputs of the white light sources is offset by an increase in light quality (the eye is more perceptive to white light than yellow light).

Scheme 2 – Dimming and Constant Light Output
Installing a Central Management System (CMS) enables a number of cost saving maintenance efficiencies to be realised, including part-night dimming and Constant Light Output (CLO). Dimming reduces the light output during low traffic periods (eg. midnight to 6am) to the next category light level of the Standard. A reduction in light levels of 50% is barely perceptible to the human eye. CLO enables energy savings by limiting the excessive light output of luminaires in their early life. The degree to which dimming and CLO technology could be propagated across the network was not assessed in detail in the first report in this investigation.

This paper contains detailed analysis around costings and implementation options of the various technologies to enable Auckland Transport to implement this technology across the street lighting network.

4 Client Commission

Opus International Consultants issued the report "Street Lighting Energy Strategy – High Level Discussion Paper" to Auckland Transport in February 2012.

Having identified this paper, Auckland Transport has asked Opus to provide more detail concerning the various options available for energy savings by adoption of the latest generation of street lighting technology.

Client requirements are:

- More detailed modelling across different initial capital implementation cases, reporting the following for each case;
    - Upfront capital;
    - Annual energy cost;
    - Annual luminaire replacement cost;
    - Annual maintenance visit cost;
    - Projected payback;
    - Whole of life savings.
- Thorough documentation of the assumptions informing the above model;
    - Settlement on a preferred white light technology, justifying this with detail around relative advantages and disadvantages of proposed white light alternatives;
    - Further investigation into requirements for Scheme 2 – Dimming and Constant Light Output.

Secondary drivers for the client include:

- Addressing current non-compliance with street lighting standards in conjunction with the implementation of these schemes.

5 Analysis – Scheme 1 – Replacement of HPS with White Light

Further to the research completed and solutions identified in the previous report ("Street Lighting Energy Strategy – High Level Discussion Paper", February 2012), Opus has completed a detailed analysis of the savings feasible under this proposed scheme – the one-for-one replacement of 70W HPS luminaires on Category P3 and P4 classified roads respectively with a lower power white light source of equal light distribution.

This paper gives additional options for progressive scheme implementation, differing from the 100% CAPEX solution originally offered in the High Level Report. This report assesses 2 different types of capital investment model, analysed in 5 different case studies as follows:

- 4 cases of varied initial capital investment, with the balance of the investment being rolled out through BAU luminaire replacement across the network as the existing 70W stock fails. The initial (Year One) capital investment for each modelled case is:
    - The original 100% CAPEX solution;
    - 50% CAPEX, followed by ongoing replacement at life expiry;
    - 33% CAPEX, followed by ongoing replacement at life expiry;
    - 10% CAPEX, followed by ongoing replacement at life expiry;
- 1 case of phased scheme implementation across a 5 year period, similar to the Los Angeles project model, where 20% of the asset is replaced in annual phases over a 5 year period.

Progressive implementation allows the adoption of new iterations of the white light technology as these are developed and released across the phase-in period, additional time to assemble a robust supply chain and contract labour, together with a reduced initial capital investment. In addition, phased acquisition would enable Auckland Transport to take advantage of likely reductions in acquisition costs as the technology matures still further and manufacturers production runs increase. Progressive implementation also recognises that available installation resources dictate timeframes.

5.1 Scope of Scheme

The scope of the scheme is unchanged from that discussed in the previous report ("Street Lighting Energy Strategy – High Level Discussion Paper", February 2012). That is:

- To substitute existing 70W HPS luminaires on roads categorised as P3 (NZ), P3R, P4, and P4R under the current version of AS/NZS 1158 across the Auckland Transport with white light sources.

It should be noted that this scheme does not address compliance with street lighting standards. It proposes one for one replacement of existing HPS luminaires with white light technology to enable a like for like cost comparison. Achieving compliance across the entire region will require an additional investment over and above like for like replacement, the scale of which can be determined with a detailed survey.

5.2 Scheme Benefits

The primary long-term savings-generating benefits of the scheme are as follows:

5.2.1 Lower Power Consumption

Modern street lighting fittings employing white light sources consume less power for a given light distribution. Opus has objectively assessed luminaires on the AT-HALL and AT-LALL approved luminaire lists to establish which luminaires are acceptable as substitutes for 70W HPS technology – see Section 4.4 and Appendix B.

5.2.2 Improvement of Stock

Modern street lighting fittings are required by AS/NZS 1158 Part 6:2010 to have a design life of 20 years. This is achieved through solid construction and wear-resistant materials. The current stock of 70W HPS luminaires can reasonably be expected to have a 15 year expected life, although failure at the 6 year point has been experienced.[1]

5.2.3 Reduced Maintenance Visits

Modern HPS luminaires require at least 2 maintenance visits between replacements of the luminaire. This is a function of the rated average life of the lamp (approx. 6/7 years for modern 70W HPS lamps). In the case of LED luminaires, much longer periods between maintenance visits are possible, due to LED luminaires not requiring re-lamping. Maintenance visits can be reduced to just 1 between luminaire replacements (ie. 10 year intervals) to clean the luminaire and inspect the asset (ie. bracket arm, pole) for condition. This is possible because the lumen depreciation[2] across a 10 year period is still tolerable for the LED technologies studied.

5.2.4 Asset Audit Opportunity

An extensive upgrade of Auckland Transport's network provides an ideal opportunity to comprehensively update RAMM records for that part of the network which is being upgraded. Enhanced knowledge of the network will assist with future Asset Management Plans, and the 10 Year, 3 Year, and 1 Year Forward Work Plans. Cost benefits realised from this opportunity are secondary benefits and are therefore not factored into this report.

[1] Feedback from Auckland Transport street lighting team.
[2] The rate at which the light output from a fitting reduces, due to dirt build-up on the luminaire glass and the diminishing output from the light source (HID lamp or LED modules) itself.

5.2.5 Lamp and Luminaire Bulk Maintenance Opportunity

This proposed bulk upgrade also offers the opportunity to introduce bulk lamp and luminaire replacement policy, reducing costly spot maintenance visits. New assets installed in bulk during product phase-in can be serviced in bulk as that stage's stock ages in unison.

It is assumed for the purposes of comparison that a reactive approach to 70W HPS lamp and luminaire replacement would continue to be employed in the future should this capital works project not be commissioned, and that this approach would also be employed in the servicing of remnant HPS luminaires in the 50%, 33%, and 10% case studies.

5.3 Cost Savings & Options for Implementation

Significant and achievable savings are possible under this scheme. Opus has examined five different models of progressive implementation of these technologies across the scope of the scheme. These options are provided purely for comparative purposes to illustrate the variations in return on investment in terms of payback period for varying initial capital investments. 2012 costs have been used rather than NPV for all costings.

100% LED Implementation					
	Initial Investment (Year One)	**Initial Capital Cost (Year One) ($M)**	**Whole of Life Savings ($M)**	**Payback Period**	**Time to Complete**
Case 1	100%	25	38	8 years	1 year
Case 2	50%, followed by replacement of remaining HPS stock on life expiry	13	28	11 years	10 years
Case 3	33%, as above	8	24	9 years	13 years
Case 4	10%, as above	3	21	4 years	18 years
Case 5	5yr Phase-In (20% / year)	5	36	9 years	5 years
100% CMH Implementation					
Case 1	100%	24	21	10 years	1 year
Case 2	50%, followed by replacement of remaining HPS stock on life expiry	12	10	15 years	10 years
Case 3	33%, as above	8	7	17 years	13 years
Case 4	10%, as above	2	4	19 years	18 years
Case 5	5yr Phase-In (20% / year)	5	19	11 years	5 years
100% Cosmopolis Implementation					
Case 1	100%	24	24	10 years	1 year
Case 2	50%, followed by replacement of remaining HPS stock on life expiry	12	13	14 years	10 years
Case 3	33%, as above	8	9	16 years	13 years
Case 4	10%, as above	2	5	5 years	18 years
Case 5	5yr Phase-In (20% / year)	5	22	10 years	5 years

Table 1 - Whole of Life Comparisons between Technologies

See Appendices for the model outputs and the assumptions upon which they are built. Note – this table includes CMS costs and savings (see Section 6).

5.3.1 Post Implementation Savings

Significant and achievable savings are possible under Scheme 1 – 70W HPS Replacement once fully implemented, whatever the mix of initial and follow on investment.

This table shows energy savings:

White Light Source	Scheme 1 – Annual Energy Savings ($M / Annum)	Percent Savings Against 70W HPS (%)	Percent Savings Against Entire Network (%)
LED	1.1	52	9
CMH	0.5	25	4
Cosmopolis	0.7	33	6

Table 2 – Scheme 1 Only – Annual Energy Savings per Technology for Case 1: 100% Replacement

The below figures are inclusive of savings endowed by longer maintenance periods and methods

White Light Source	Annual Savings ($M / Annum)	Percent Savings Against Existing (Do Nothing) (%)
LED	2.0	46
CMH	1.1	24
Cosmopolis	1.2	28

Table 3 – Scheme 1 Only – Annual Whole of Life Savings per Technology for Case 1: 100% Replacement

The following charts show the whole of life savings per technology. All model outputs can be found in Appendices C – E.

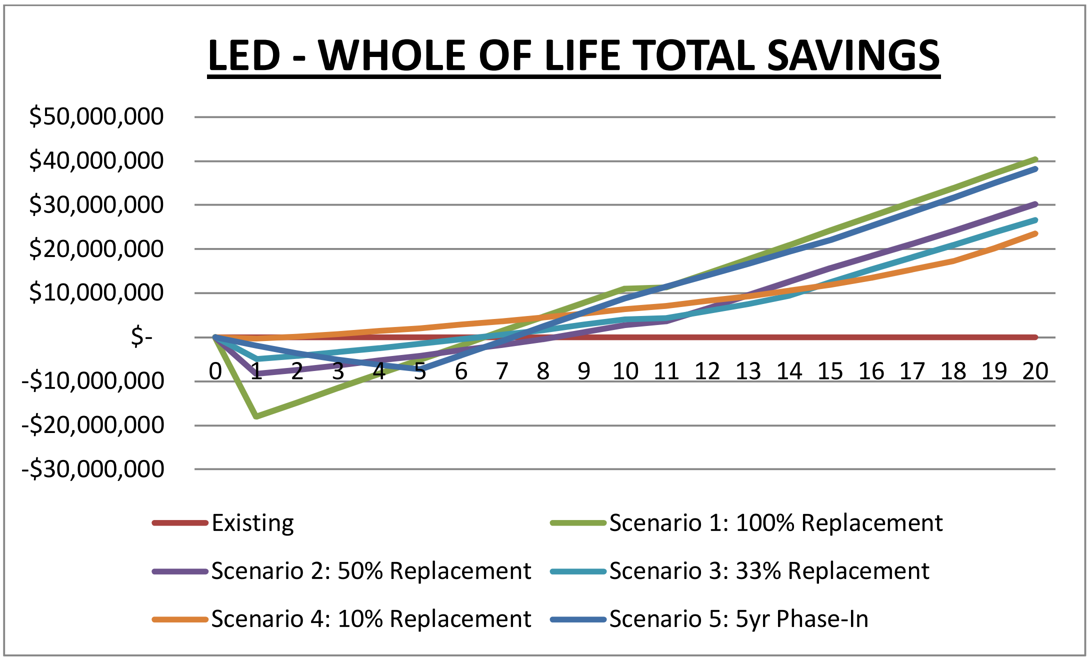


Figure 1 - LED Replacement - WoL Savings

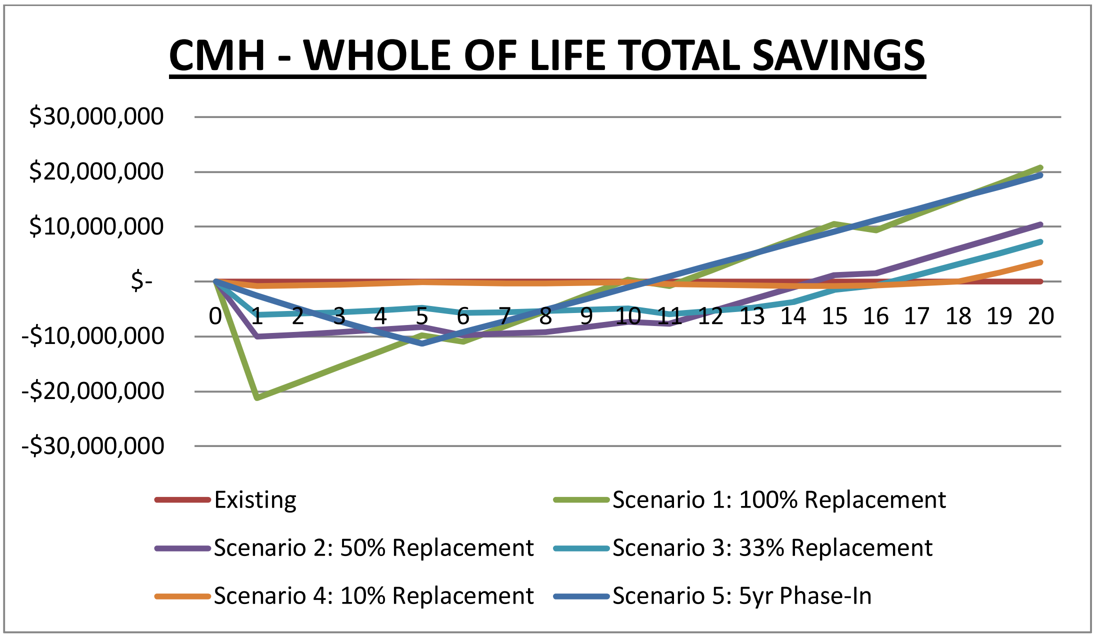


Figure 2 - CMH Replacement - WoL Savings

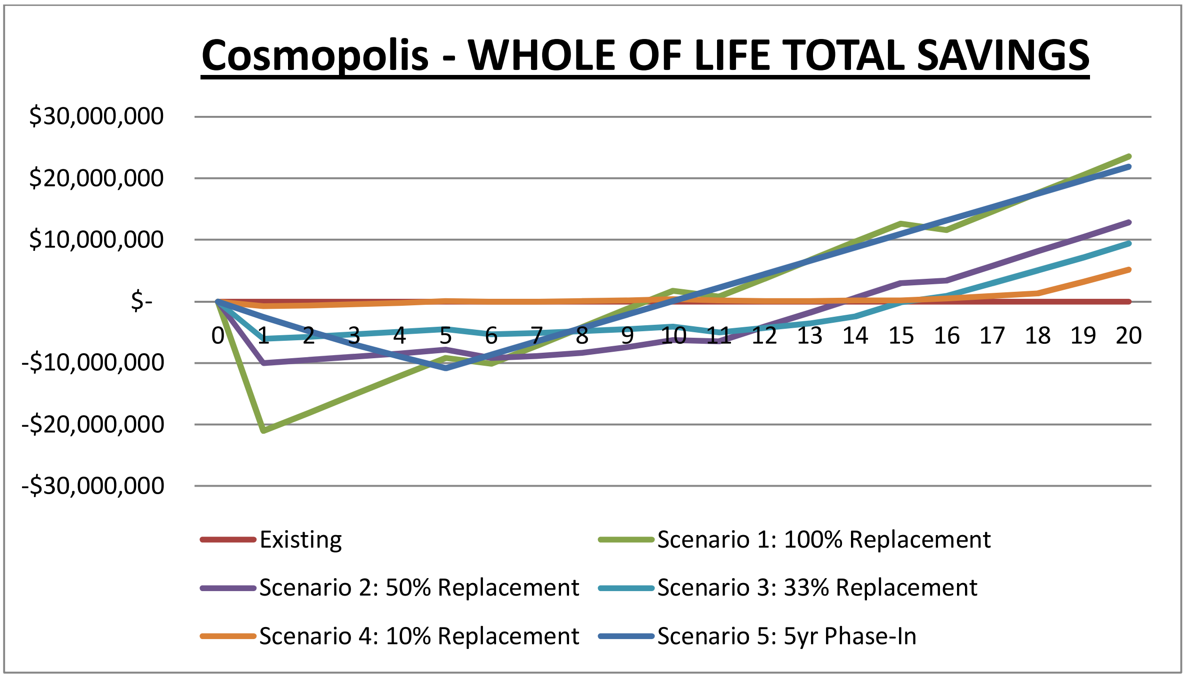


Figure 3 - Cosmopolis Replacement - WoL Savings

5.4 Methodology

The technical feasibility of this scheme is detailed in the previous report ("Street Lighting Energy Strategy – High Level Discussion Paper", February 2012).

Three types of white light source had been selected for further study into their applicability as a lower power 70W HPS replacement. These were:

1. 50W CMH ("new generation" ceramic metal halide)
2. 45W Cosmopolis (long life high output ceramic metal halide, manufactured by Philips)
3. LED (Light Emitting Diode)

Sources 1 and 2 above are both High Intensity Discharge (HID) lamp types, which can be compared like-for-like with a sample 70W HPS lamp inside a modern luminaire to ascertain equality of light distribution, and therefore suitability as a substitute for the existing HPS lamp.

Source 3 (LED) differs, in that it cannot be divided into lamp and luminaire. An LED luminaire is an electronic device which must be assessed against an existing 70W HPS luminaire and lamp as a complete unit, to understand whether the LED fitting in question can be considered a fair substitute for the existing luminaire in a like-for-like replacement.

Our studies for this detailed paper have shown that all three sources may be considered suitable like-for-like replacements for existing 70W HPS lamps in the context of this scheme. However, the choice of vendor is important, because material, construction, and optics vary between suppliers. Our studies have shown that the following luminaires from the Auckland Transport HID and LED Approved Luminaire Lists (AT-HALL and AT-LALL) are the best performers. We note that for competitive tendering, other luminaires from the AT-HALL and AT-LALL should be considered.

- 50W GE Streetwise CMH lamps may be used in the Schreder Nano or AEC Kaos 1 luminaires;
- 45W Cosmopolis lamps may be used in the Schreder Nano luminaire;
- Ruud BetaLED Type 2M 525mA 4300k 20count LED luminaires may be used.

Detailed analysis and calculations justifying the selection of these three substitute technologies and vendors is given in Appendix B.

6 Scheme 2 – Central Management System (CMS)

6.1 Methodology

A street lighting Central Management System (CMS) may be installed in tandem with the rollout of Scheme 1 and take command of the intelligent electronic ballasts[3] within luminaires installed as a part of that scheme to add dimming and Constant Light Output (CLO) functionalities to the street lighting network, enabling additional savings.

The technical feasibility of dimming is detailed in the previous report ("Street Lighting Energy Strategy – High Level Discussion Paper", February 2012). Previous Opus reports ("Auckland City Council – Street Light Dimming Study", 2009, and "Fixed Time Dimming Study", April 2011) commissioned by Auckland Transport explain in detail the technicalities of street light dimming technology, and the many options/degrees of control available to the asset owner with such systems installed.

Part-night dimming proposes utilisation of pre-approved, centrally administered dimming profiles as the reference for reporting energy consumption. These dimming profiles are integrated into the CMS and remotely co-ordinate the operation of dimming-enabled luminaires on the network. CMS achieves this through LAN communications between the server and transmitting stations in the field called Segment Controllers or Sector Controllers, which pass on dimming instructions via RF to an antenna on the luminaire, which outputs 1-10V or DALI to the ballast.

A cheaper option (or an interim measure) not utilising any CMS is the implementation of standalone dimming control technologies recommended in the previous Opus report ("Fixed Time Dimming Study", April 2011). These technologies carry the dimming profile within the luminaire, which requires it to be approved and pre-loaded before the scheme rollout is to begin. This is not recommended on a large scale, as it is considered that the real time oversight, feedback, and database population capacity offered by a CMS should be the goal for future-conscious street lighting asset management, which is in keeping with this report's commission.

Key to the success of dimming as a cost-saving strategy is revision of the pricing procurement model which presently dictates how Auckland Transport processes its billing and pays for its energy. Traditionally, street lighting is an unmetered supply. Reported operating hours are based on energy profiles[4]. Auckland Transport's energy is presently billed according to the rated power of the luminaires on the street lighting network. The temporary dimming of a fitting saves energy, but does not change its rated power, meaning a cost saving would not be realised under the present billing regime. A CMS solution would require the Segment Controllers to be registered as meters or have agreed profiles for

[3] The ballast is a separate electrical device in the luminaire that drives the lamp. Old technology ballasts are inefficient, wire-wound units which waste energy and do not effectively care for the lamp. New technology ballasts are efficient, digital electronic devices which carry facility to dynamically control light output.

[4] Energy profiles are attributed to each lamp type as Total Circuit Watts, which are then applied to the total number of assets held on the respective RAMM database for that lamp type to determine the total level.

luminaires under their control, and these fittings to be removed from existing payment mechanisms to avoid paying for them twice. Likewise, luminaires governed by standalone dimming technologies would require their specific dimming profiles to be approved as energy profiles and noted as a way to discount the existing rated power of the dimmed luminaire.

Opus have been engaged by Auckland Transport to facilitate a methodology where by the Electricity Authority recognises the energy profiles for new technologies under Part J Schedule J5 of the Electricity Governance Rules. Currently no such framework exists. This work has been ongoing now for the past 18 months. The outcome will be an approved methodology to enable Local Authorities to utilise new technology and be able to realise the benefits through reduced energy cost.

Trials have primarily involved single street light points on photocells with part-night dimming. We are currently also investigating systems where a group of street lights are controlled by a Segment Controller, which has power monitoring in-built in its software. The next phase of the investigation will be to consider the Segment Controller as an "approved meter" by the Electricity Authority.

One important additional feature of CMS systems is the Constant Light Output (CLO) facility. This feature effectively monitors lamp output and keeps it at a constant level, lowering its output during its early life when it tends to burn excessively brightly, resulting in overlit roads compared to the design target. This feature is not available in any standalone technology that we have become aware of during our research.

6.2 Scope of Scheme

It is proposed that this dimming capability would be incorporated within **Scheme 1 – Replacement of HPS with White Light Luminaires on Category P Roads**, thus increasing the savings possible per luminaire replaced while still making only one visit to achieve the replacement, increasing the economic benefit of the scheme.

It is proposed that dimming is limited to 70W luminaires on P3 roads, with the intention that a dimming profile is transmitted such that these luminaires would be dimmed to a level complying with lighting category P4. It is considered that roads ordinarily categorised P4 would be unsafe if dimmed to any lower lighting level. (Note Category P5 is not utilised in NZ although part of the AS/NZS 1158 Standard).

It is unknown exactly what percentage of 70W luminaires (proposed for replacement under Scheme 1) are on P3 roads or P4 roads, therefore an assumption has been made for this figure (see Appendix B).

The benefits of CLO functionality are available only to HID luminaires. LED does not benefit from CLO savings.

6.3 Possible Energy Savings

For the purposes of this study, Opus has created a sample dimming profile to establish the potential savings available through the dimming of luminaires on P3 roads through the implementation of this scheme.

The sample dimming profile proposes that the luminaire operates as follows:

- Switch on at dusk
- Run at 100% output until midnight
- Dim to P4 Lighting Category levels at midnight[5]
- Elevate back to 100% output at 6am
- Switch off at dawn

This profile can be represented graphically as follows:

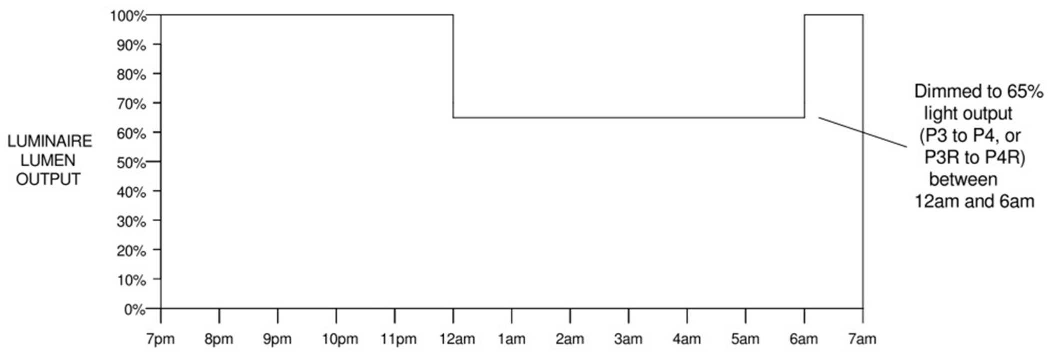


Figure 4 – Sample Dimming Profile - Light Output

This dimming profile represents 18% less lumen (light) output from the luminaire across a 12 hour period. CMH and Cosmopolis lamps dim to 65% lumen output when power input is reduced to 70%, whereas LED achieves 65% dimming when power input is reduced to 65%.

[5] In New Zealand, dimming from P3 (NZ) to P4 (or P3R to P4R) levels involves the lowering of luminaire output to P4 or P4R LTPs (Light Technical Parameters) as described in AS/NZS 1158.3.1:2005 Table 2.6. The key LTP to obtaining lighting compliance is E_{ph}. Simplistically, this can be achieved by dimming light output by 35%, such that E_{ph} is lowered from 0.22 to 0.14 lux (P3 (NZ) to P4), or 0.11 to 0.07 lux (P3R to P4R).
Note that this approach will not create compliance on existing non-compliant roads to which this scheme is applied, but would dim to P4 or P4R compliant levels on already compliant P3 (NZ) or P3R roads respectively, assuming other (E_h and U_{E2}) LTPs are not compromised.

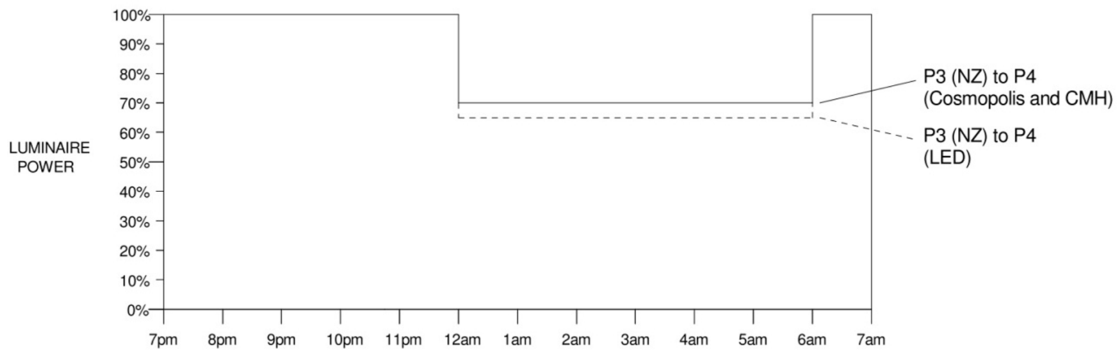


Figure 5 – Sample Dimming Profile - Power Input

This equates to the following power savings across the same 12 hour period:

	Luminaire Rated Power	Luminaire Dimmed Power	Dimmed Power Savings / Luminaire
CMH	58W	50W	13.5%
Cosmopolis	52W	45W	13%
LED	37W	31W	17.5%

Table 4 – Averaged Profile Power Savings through Dimming

As mentioned, we have assumed this scheme may be applied to 50% of luminaires in Scheme 1 – that is, 50% of 70W HPS luminaires are on P3 roads and may be dimmed with this technology to P4 during the part-night window identified in the above sample dimming profile.

Power savings are also available through the utilisation of CLO technology. Exact energy savings achievable for the white light substitute technologies in this study are as yet not completely understood, however available documentation suggests a 5% energy savings for all HID luminaires utilising this technology is readily achievable.

These two power saving options offer the following combined savings:

White Light Source	Annual Energy Savings ($M / Annum)	Percent Savings Against 70W HPS (%)	Percent Savings Against Entire Network (%)
LED	0.09	4%	<1%
CMH	0.18	8%	1%
Cosmopolis	0.16	7%	1%

Table 5 – Scheme 2 – Annual Energy Savings per Technology through Dimming and CLO

6.4 Costs

At the time of writing, acquisition and installation costs for CMS solutions was still being considered. Options include total ownership through capital purchase, or the lease of the system from the vendor. However, we estimate based on previous investigations that the capital cost for this dimming scheme to be around 20% of that of the 70W luminaire replacement scheme, ie. ~**$4M**, if both schemes are rolled out together. Implementation of this scheme will also allow better monitoring and asset management, giving increased maintenance and operational savings to complement the energy savings made available through the dimming function of the system.

6.5 Discussion

The cost of a CMS is high ($4M) in relation to the savings likely to accrue. However, if all luminaires in the AT asset base were progressively added to CMS control, dimming would enable further savings to be realised. Aside from energy savings, CMS provides the following advantages:

- Enablement of better forecasting and planning through network information feedback;
- Improved group/spot replacement as no scouting[6] is required;
- Predictive information about lamp failure, and;
- Data collection that tracks lamp illumination and can be used to claim warranty replacement, establish unbiased product and supplier selection criteria, and validate bills for the system.

[6] "Scouting" refers to nightly patrols that maintenance contractors will action to detect lamp failures not reported by the public.

7 Conclusion

- The implementation of any of the Scheme 1 – 70W HPS Replacement technologies studied in this paper offers significant energy savings and maintenance efficiencies, resulting in major whole of life cost savings without degrading existing lighting levels on Auckland Transport's road reserves.

- Of the three white light technologies considered, LED offers the greatest savings. This is primarily due to a rapid maturing of this technology which has resulted in unit costings and light output on par with HID alternatives for much lower power input.

- 100% Year One installation using LED technology gives the greatest predicted whole of life savings of $38M, however this also requires the greatest initial capital investment of approximately $25M.

- 10% Year One installation using LED technology followed by ongoing replacement at life expiry offers the quickest payback on the initial investment (4 years) and the least upfront capital ($3M), but offers the lowest whole of life savings ($21M) and the longest programme for completion (18 years).

- A fixed term rolling replacement implementation programme offers advantages over both the above options; the 5 Year Phase-In case is the best example of this. It offers whole of life savings of approximately $36M, which is close to that which would be achieved with a 100% up front solution, whilst being much better matched to installation resources and allowing advantage to be taken of the likelihood of reducing unit costs over time.

- Although three different technologies have been studied, the case for the installation of LED technology outweighs the CMH and Cosmopolis alternative cases comprehensively.

- Maintenance savings from dimming and CLO technology that might come under Scheme 2 have not been quantified in this study, but are nonetheless likely to be appreciable.

- Dimming and Constant Light Output savings achieved through implementation of Scheme 2 (Central Management System) are low in relation to capital cost, but must be viewed from the perspective that many of the maintenance efficiencies and operating advantages that such a system offers have been deemed secondary benefits for the purposes of this study and are not captured by the model. In addition, the value of a CMS will increase as other parts of the street lighting asset base are added to it.

- The modernising of 40% of the network stock offers an excellent opportunity to audit and update records in RAMM, improving the reliability of Auckland Transport's key asset management reference.

8 Recommendations

- We recommend that Auckland Transport implement the LED 5 Year Phase-In case assessed in this report, ie. the replacement of 40,000 70W HPS luminaires with the proposed LED luminaire on P3 and P4 Category roads, progressing the investment across Greater Auckland in a geographical fashion, 20% of the network per year.

- We recommend that a detailed Work Plan be commissioned to govern implementation of the above recommendation.

- We recommend that rollout of a Central Management System in tandem with the above scheme be considered.

Appendix A – Calculation of Scheme 1

Amalgamation of Combined Asset Management Database (RAMM) Information for Previous Territorial Authorities

	Auckland City Council	Manukau City Council	Franklin District Council	North Shore City Council	Waitakere City Council	Papakura District Council	Rodney District Council	Total
# 70W HPS Fittings[7]	14,181	13,550	1,218	2,462	4,378	2,336	1,571	**39,695**
# Luminaires Total[8]	32,611	24,256	2,444	16,985	13,845	4,025	5,800	**99,966**
70W % of Total	43.5	55.9	49.8	14.5	31.6	58.0	27.1	**39.7**

Table 6: Total 70W HPS Luminaires Eligible for Replacement with White Light Source

[7] "# 70W HPS Fittings" is the sum of results arrived at by filtering on the Lamp Wattage field in the RAMM database, minus 10% (circumspectly attributed to discount existing white light sources and 70W HPS luminaires in use on V Category roads). (See Section 5.1.4)

[8] "# Luminaires Total" is the sum of all luminaires in the RAMM database.

Appendix B – Model Assumptions

Justification of Selection of White Light Luminaires as Suitable Substitutes for Existing 70W HPS Luminaires

All lamps and luminaires examined in the course of this study have been sourced from the current Auckland Transport Approved Luminaire List and are therefore assumed fit for installation on the Greater Auckland street lighting network without hindrance. All are also assumed to comply with the 20 year design life requirement of AS/NZS 1158.

The approach taken has been to model each proposed alternative luminaire's light distribution in the computer modelling software package AGI32, and compare this to the incumbent technology, a 70W HPS lamp in a modern luminaire. An experienced lighting engineer would then weigh the results and consider the proposed technology suitable or unsuitable. All models share common base inputs, in order to maintain a fair comparison.

Light type	HPS	Cosmopolis™	CMH	LED
Light source	70W GE Lighting Lucalox XO	45W Philips MASTER CosmoWhite CPO-TW	50W GE Lighting StreetWise™	Ruud BetaLED Type II Medium 525mA 4300k 20count
Lumen output (lux)	6600 × 0.75 = 4950	4725	5000	N/A[9]
Time burnt	20,000 hours			80,000 hours
LMF[10]	0.88			0.83
LLMF[11]	0.86	0.88	0.71	0.90
Mounting height	8m			
Tilt	0°			
Isolines[12]	0.14 lux, 0.22 lux, 1 lux, 5 lux			

Table 7 - Luminaire Modelling - AGI Input Parameters

[9] This luminaire has used the Absolute Photometric Testing Method, meaning lumen output is not a required input to the AGI model.
[10] Extrapolated from data in Table F1: Luminaire Maintenance Factors, "AS/NZS 1158.3.1:2005"
[11] Refer to Lumen Maintenance curves in product datasheets attached.
[12] The first two figures are most relevant to the investigation, being the boundary values for P3 (NZ) (0.22 lux) and P4 (0.11 lux) in New Zealand.

Luminaires Tested	System Wattage	Suitability as Replacement
Schreder Nano 70W HPS	78W	N/A (CONTROL)
AEC Kaos 1 70W HPS	78W	N/A (CONTROL)[13]
Ruud BetaLED Type II Medium 525mA 4300k 20count	37W	Yes
Ruud BetaLED Type III Medium 525mA 4300k 20count	37W	No
AEC Kaos 1 45W CPO-T P0	52W	No
AEC Kaos 1 45W CPO-T P-1	52W	No
Schreder Nano 45W CPO-T	52W	Yes
AEC Kaos 1 50W CMH P0	57W	Yes
Schreder Nano 50W CMH	57W	Yes

Table 8 - Luminaires Modelled

Model outputs are attached to this document.

Attachments:

1. Schreder Nano 70W HPS
2. AEC Kaos 1 70W HPS
3. Ruud BetaLED Type II Medium 525mA 4300k 20count LED
4. Ruud BetaLED Type III Medium 525mA 4300k 20count LED
5. AEC Kaos 1 45W CPO-T P0
6. AEC Kaos 1 45W CPO-T P-1
7. Schreder Nano 45W CPO-T
8. AEC Kaos 1 50W CMH P0
9. Schreder Nano 50W CMH

[13] The Schreder Nano and AEC Kaos 1 are the incumbent 70W HPS luminaire technology and are therefore considered the control technology, or reference for this study.

Costing Calculations

The costing model is built upon a large number of assumptions. These are tabled below.

Operating Condition Assumptions	
Ambient operating temperature	25°C[14]
Annual hours of operation per streetlight	4,000
Component of power variable by kWh to Auckland Transport	$ 0.17/kWh
Total cost of CMS system installation	$ 4,000,000
Existing (70W HPS) BAU Model Assumptions	
Number of 70W HPS luminaires on P Category roads to be replaced	40,000
Percentage of 70W HPS luminaires on P3 (NZ)/P3R Category roads rather than P4/P4R Category roads	50%
Maintenance cost to replace 70W HPS luminaire (like for like in small BAU quantities)	$ 650
Maintenance cost to visit and relamp 70W HPS luminaire (in small BAU quantities)	$ 150
System power per 70W HPS luminaire	78W
Number of 70W HPS luminaires replaced due to expiry per year (like for like in small BAU quantities)[15]	2,100
Number of maintenance visits to 70W HPS luminaires to relamp and clean per year	5,000
LED Model Assumptions	
Bulk cost to replace 70W HPS luminaire with LED luminaires[16]	$ 525
Bulk cost to visit and clean LED luminaires	$ 50
Frequency of cleaning visits to LED luminaires required	10 years

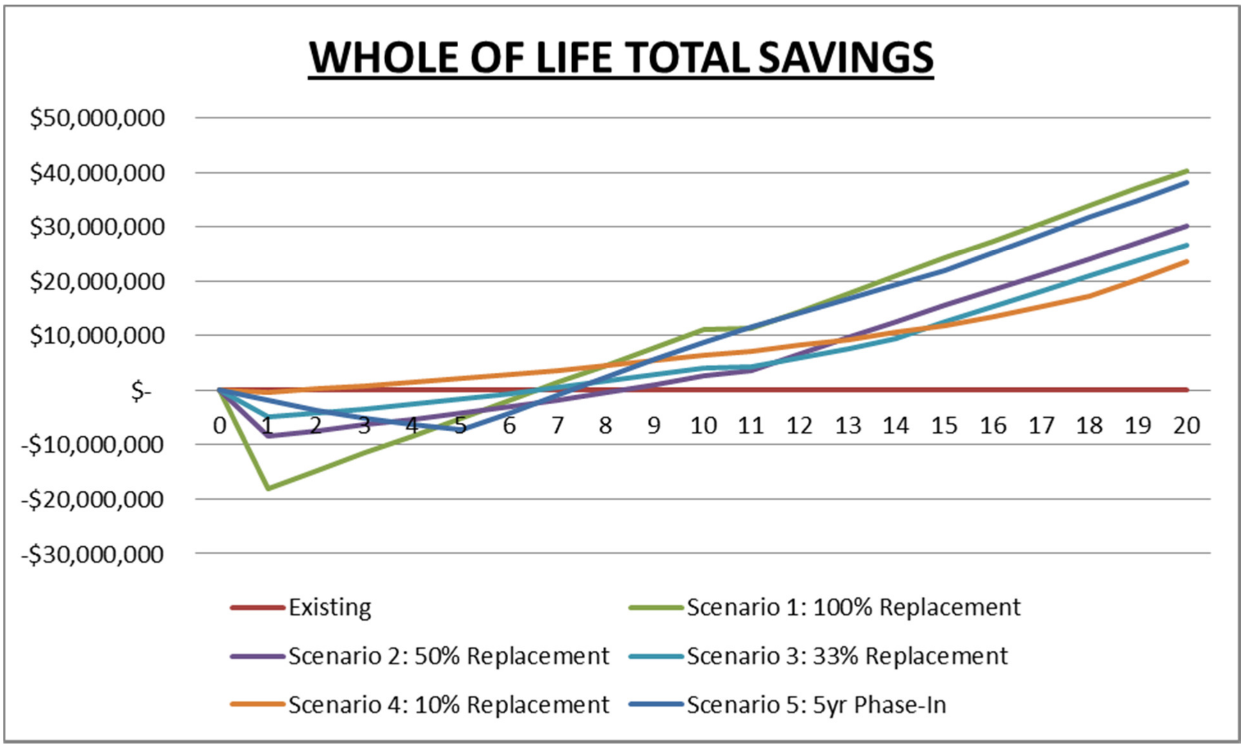
[14] As required by AS/NZS 1158. This is contrary to typical ambient night-time temperatures in Auckland.
[15] Based on client feedback on average lifetime of luminaires on the network, varying from 6 to 15 years. We have taken the median value of 10.5 years.
[16] As per quote received from Advanced Lighting Technologies.

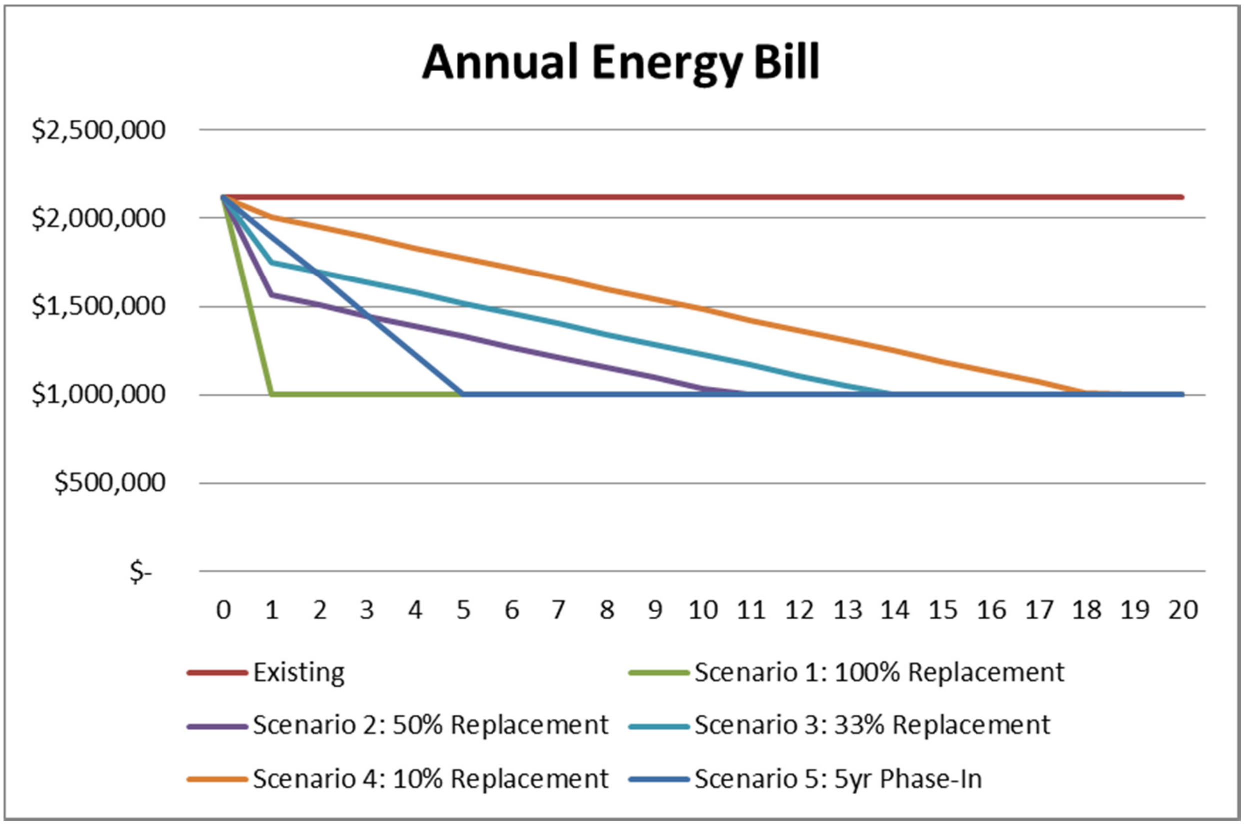
Maintenance cost to replace 70W HPS luminaire with LED luminaire (in small BAU quantities)	$ 650
Maintenance cost to visit and clean LED luminaire (in small BAU quantities)	$ 100
System power per LED luminaire	37W
CMH Model Assumptions	
Bulk cost to replace 70W HPS luminaire with 50W CMH luminaires (including DALI/1-10V dimming enabled electronic ballasts)	$ 500
Bulk cost to visit, relamp, and clean 50W CMH luminaires	$ 100
Frequency of relamping and cleaning visits to 50W CMH luminaires required	5 years
Maintenance cost to replace 70W HPS luminaire with 50W CMH luminaire (in small BAU quantities)	$ 650
Maintenance cost to visit, relamp, and clean 50W CMH luminaire (in small BAU quantities)	$ 150
System power per 50W CMH luminaire	56W
Cosmopolis Model Assumptions	
Bulk cost to replace 70W HPS luminaire with 45W Cosmopolis luminaires (including DALI/1-10V dimming enabled electronic ballasts)	$ 500
Bulk cost to visit, relamp, and clean 45W Cosmopolis luminaires	$ 100
Frequency of relamping and cleaning visits to 45W Cosmopolis luminaires required	5 years
Maintenance cost to replace 70W HPS luminaire with 45W Cosmopolis luminaire (in small BAU quantities)	$ 650
Maintenance cost to visit, relamp, and clean 45W Cosmopolis luminaire (in small BAU quantities)	$ 150
System power per 45W Cosmopolis luminaire	52W

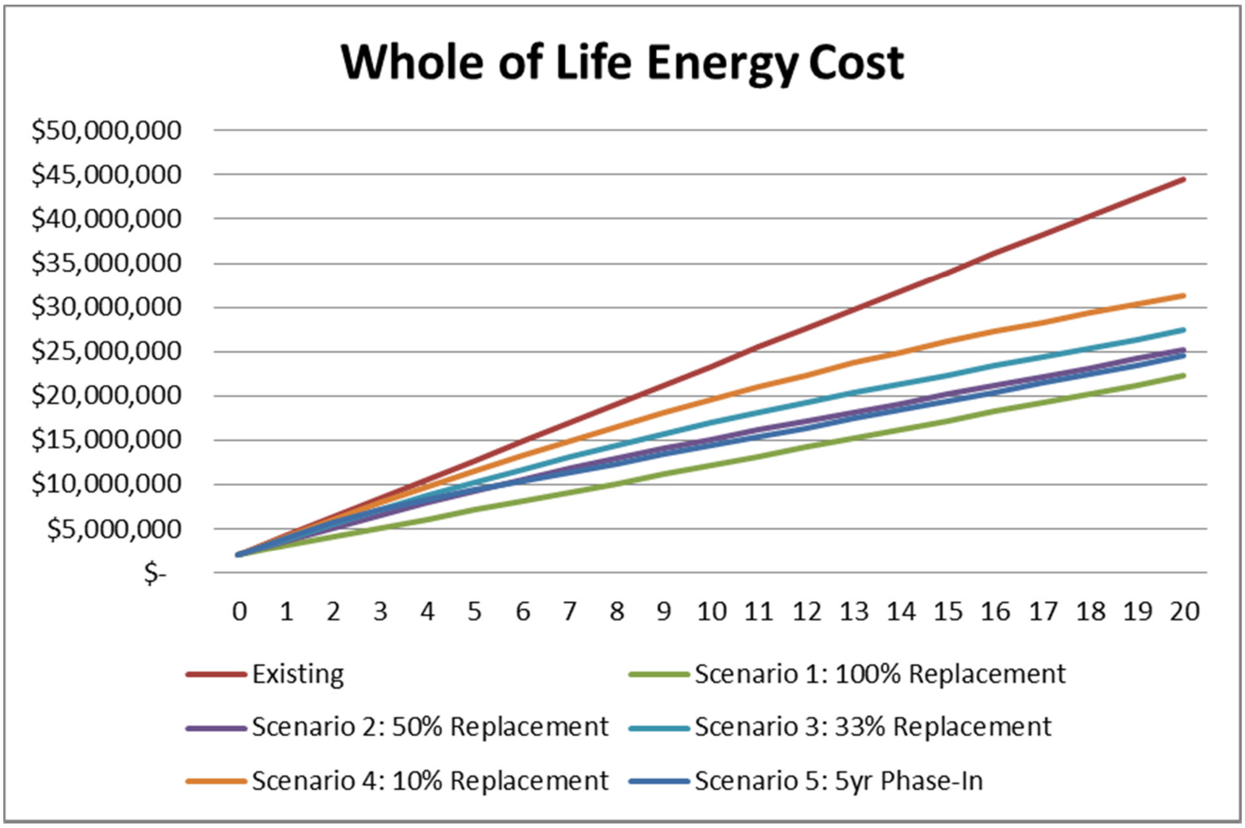
Table 9 – Assumptions

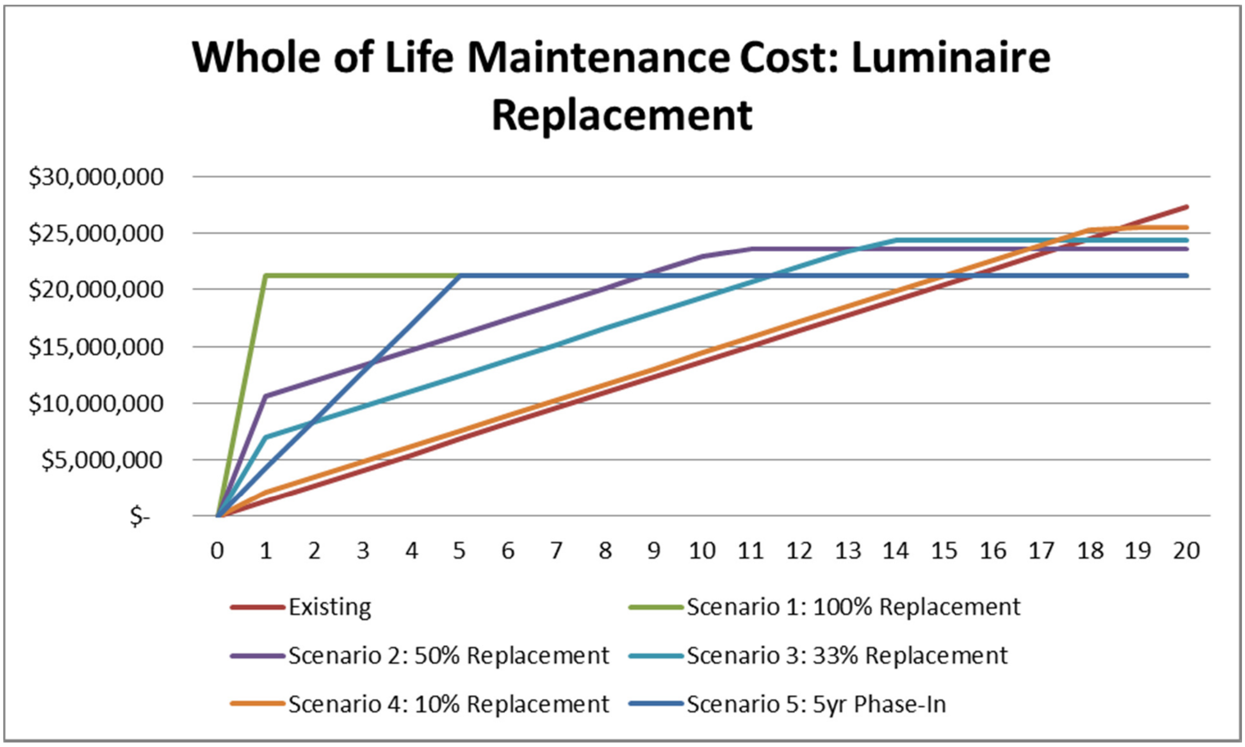
Appendix C – 70W HPS to LED

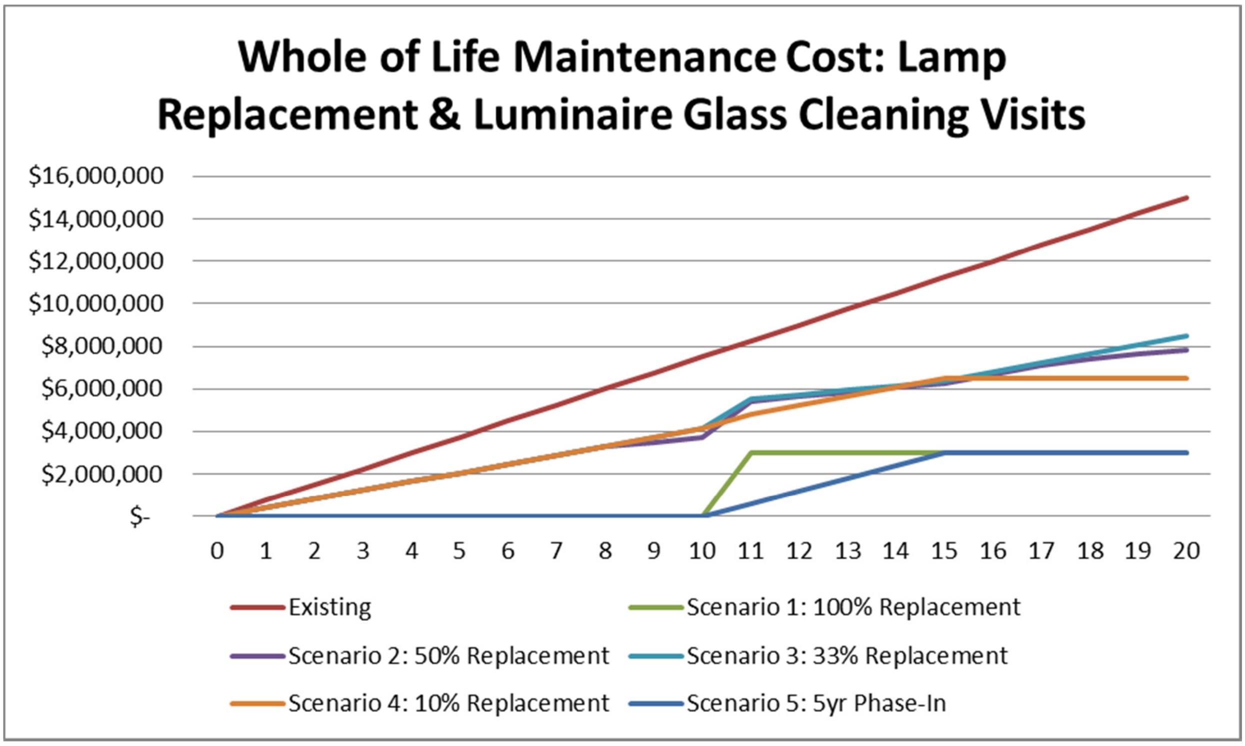
Without Dimming






Whole of Life Energy Cost
$50,000,000
$45,000,000
$40,000,000
$35,000,000
$30,000,000
$25,000,000
$20,000,000
$15,000,000
$10,000,000
$5,000,000
$-
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Existing
Scenario 1: 100% Replacement
Scenario 2: 50% Replacement
Scenario 3: 33% Replacement
Scenario 4: 10% Replacement
Scenario 5: 5yr Phase-In


Whole of Life Maintenance Cost: Luminaire Replacement
$30,000,000
$25,000,000
$20,000,000
$15,000,000
$10,000,000
$5,000,000
$-
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Existing
Scenario 1: 100% Replacement
Scenario 2: 50% Replacement
Scenario 3: 33% Replacement
Scenario 4: 10% Replacement
Scenario 5: 5yr Phase-In


Whole of Life Maintenance Cost: Lamp Replacement & Luminaire Glass Cleaning Visits
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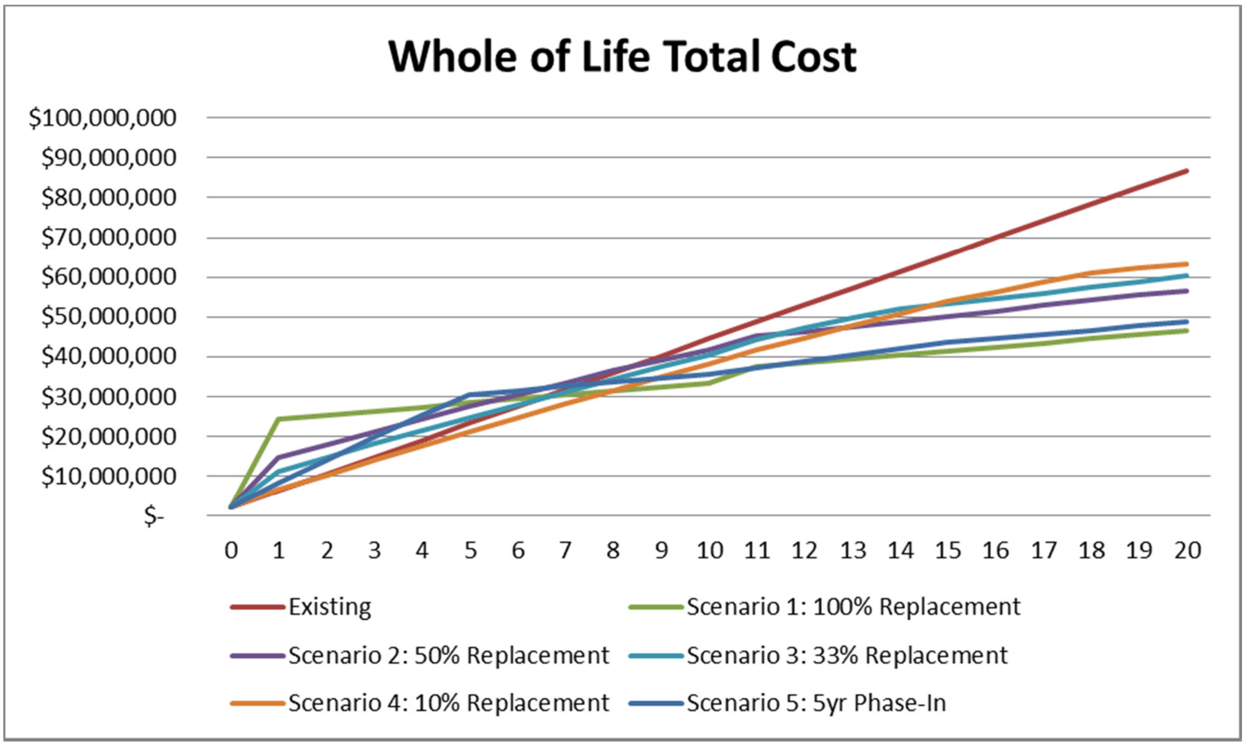
$14,000,000
$12,000,000
$10,000,000
$8,000,000
$6,000,000
$4,000,000
$2,000,000
$-
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Existing
Scenario 1: 100% Replacement
Scenario 2: 50% Replacement
Scenario 3: 33% Replacement
Scenario 4: 10% Replacement
Scenario 5: 5yr Phase-In


Whole of Life Total Cost
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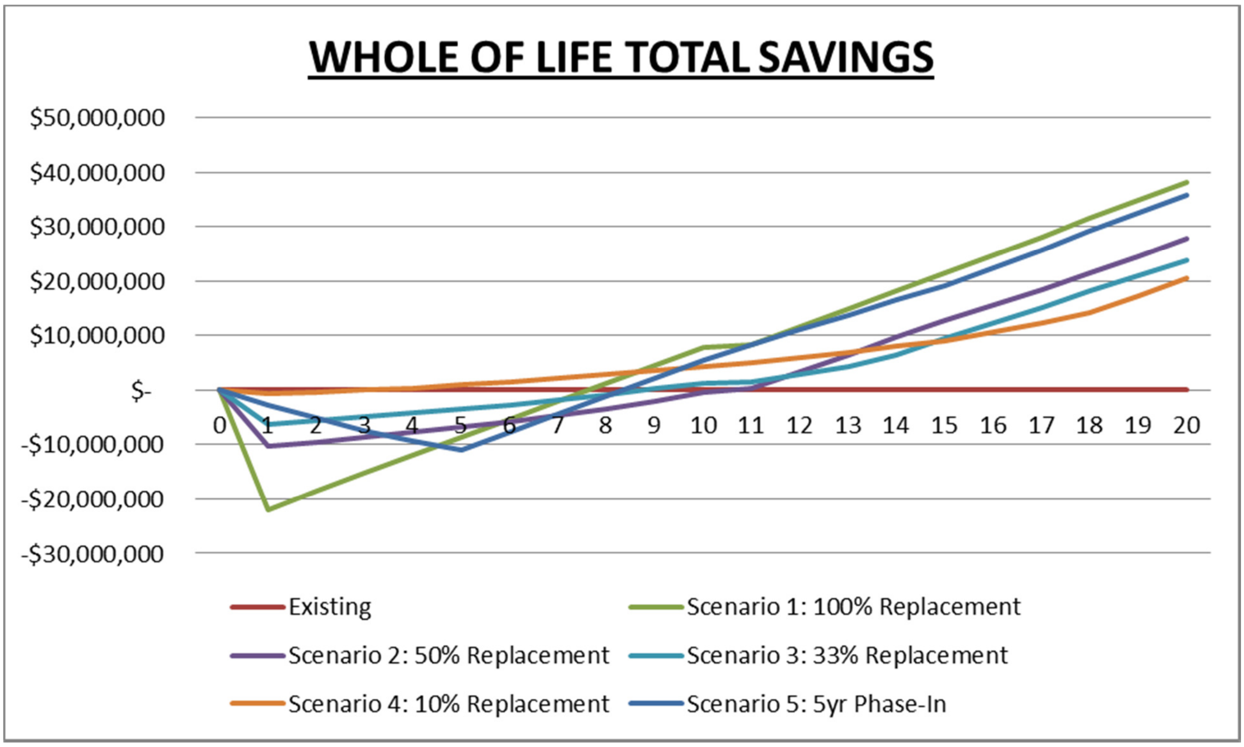
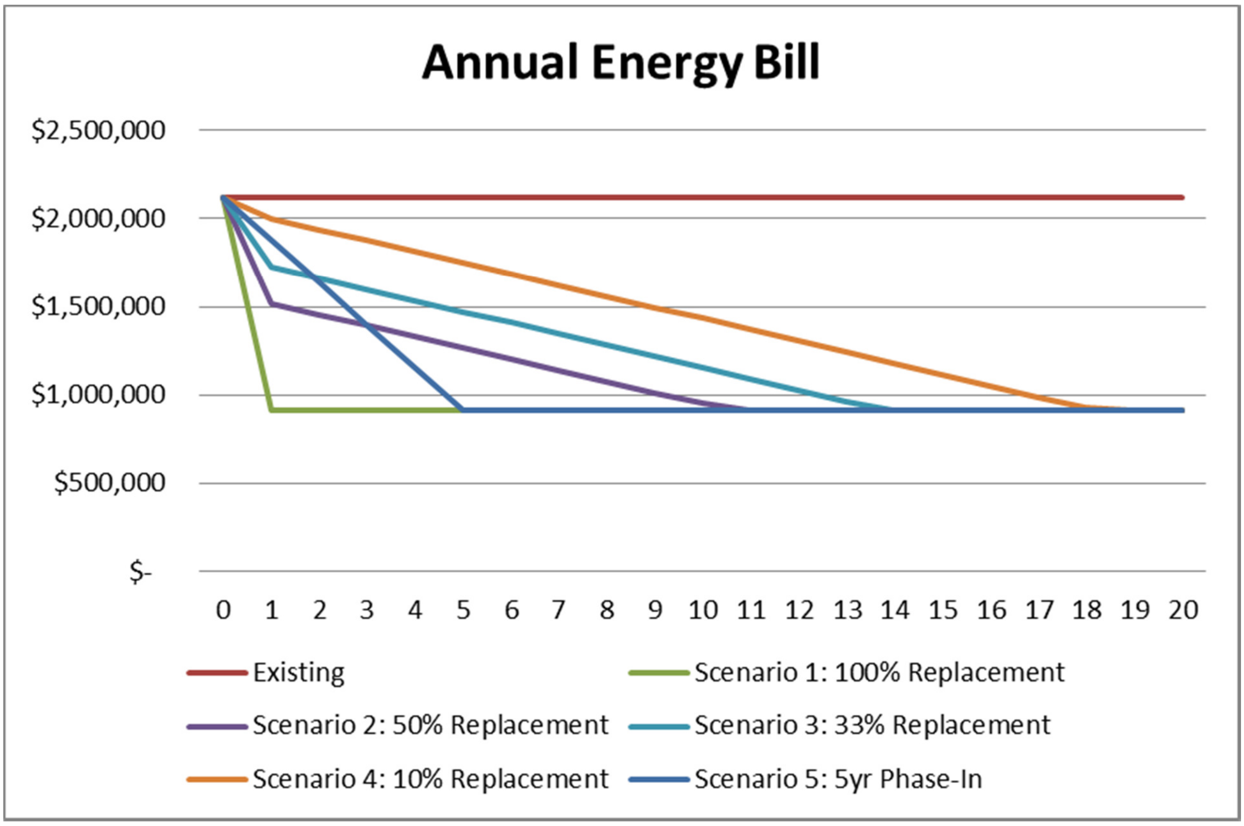
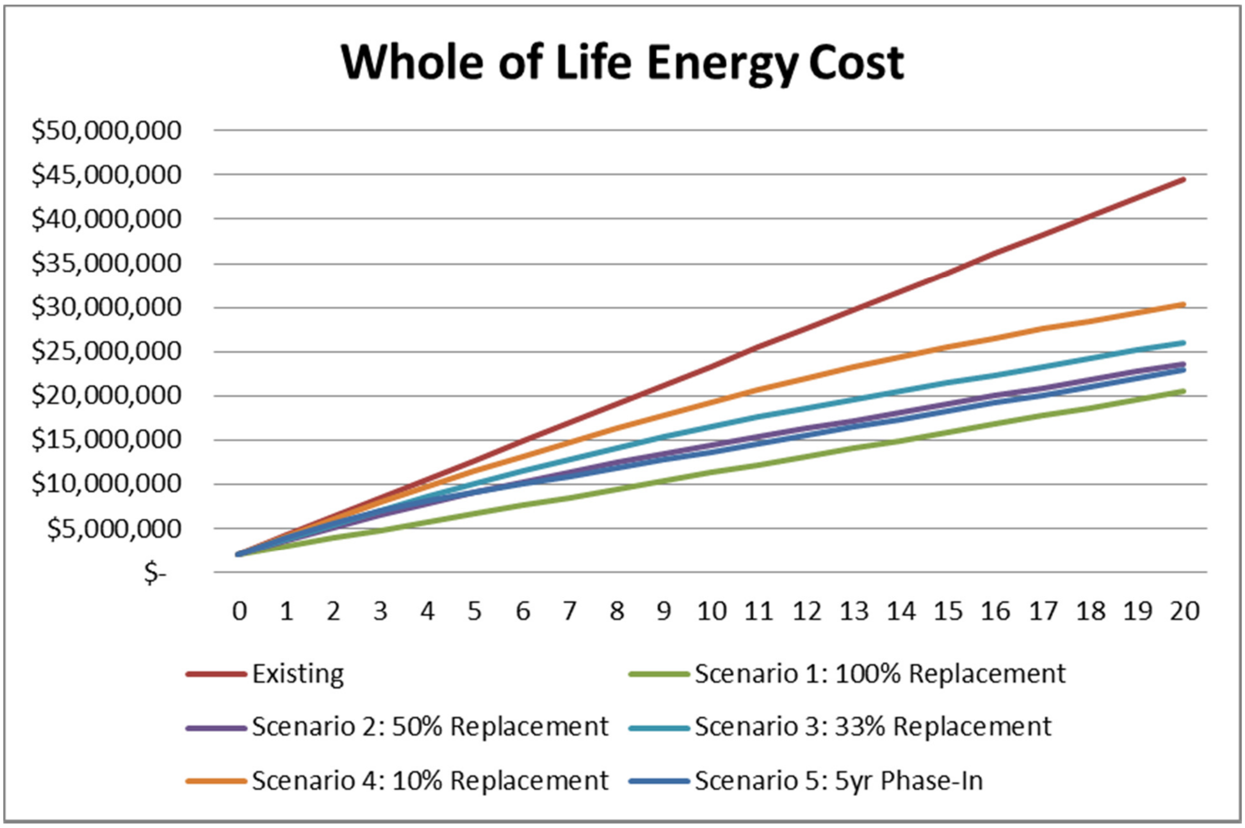
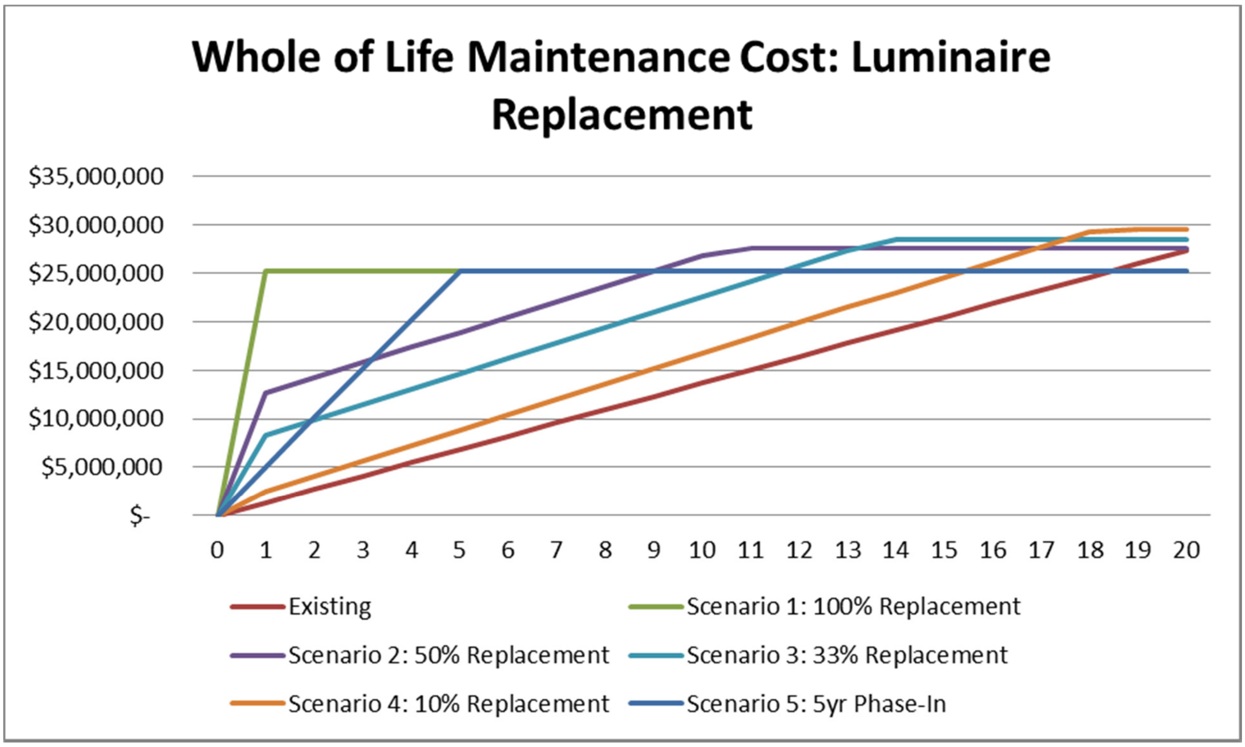
$90,000,000
$80,000,000
$70,000,000
$60,000,000
$50,000,000
$40,000,000
$30,000,000
$20,000,000
$10,000,000
$-
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Existing
Scenario 1: 100% Replacement
Scenario 2: 50% Replacement
Scenario 3: 33% Replacement
Scenario 4: 10% Replacement
Scenario 5: 5yr Phase-In

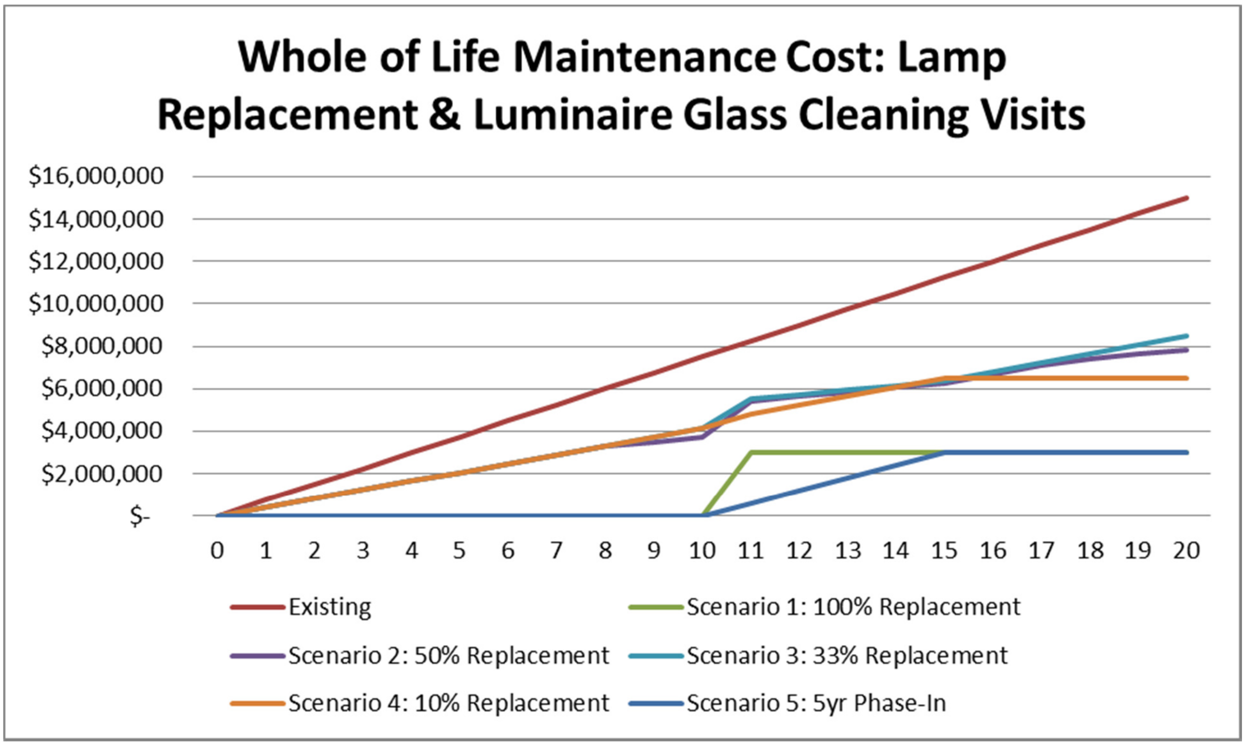
With Dimming

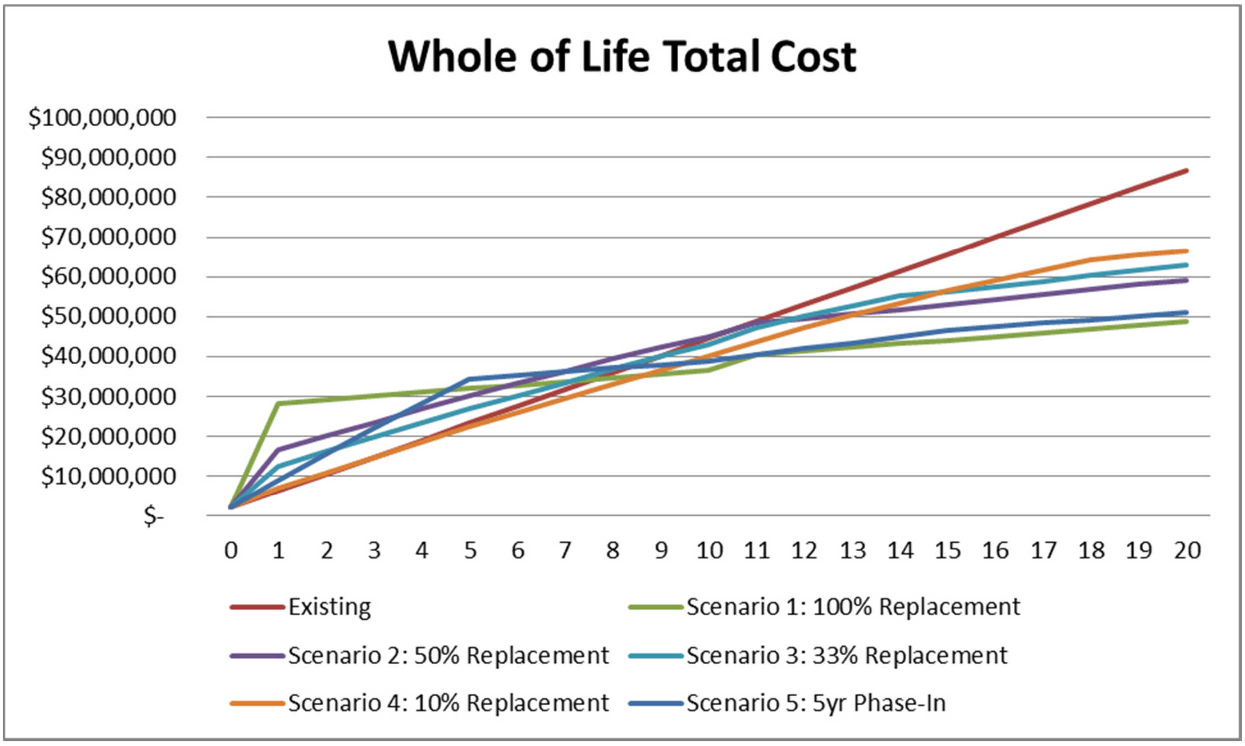





Whole of Life Energy Cost
$50,000,000
$45,000,000
$40,000,000
$35,000,000
$30,000,000
$25,000,000
$20,000,000
$15,000,000
$10,000,000
$5,000,000
$-
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Existing
Scenario 1: 100% Replacement
Scenario 2: 50% Replacement
Scenario 3: 33% Replacement
Scenario 4: 10% Replacement
Scenario 5: 5yr Phase-In

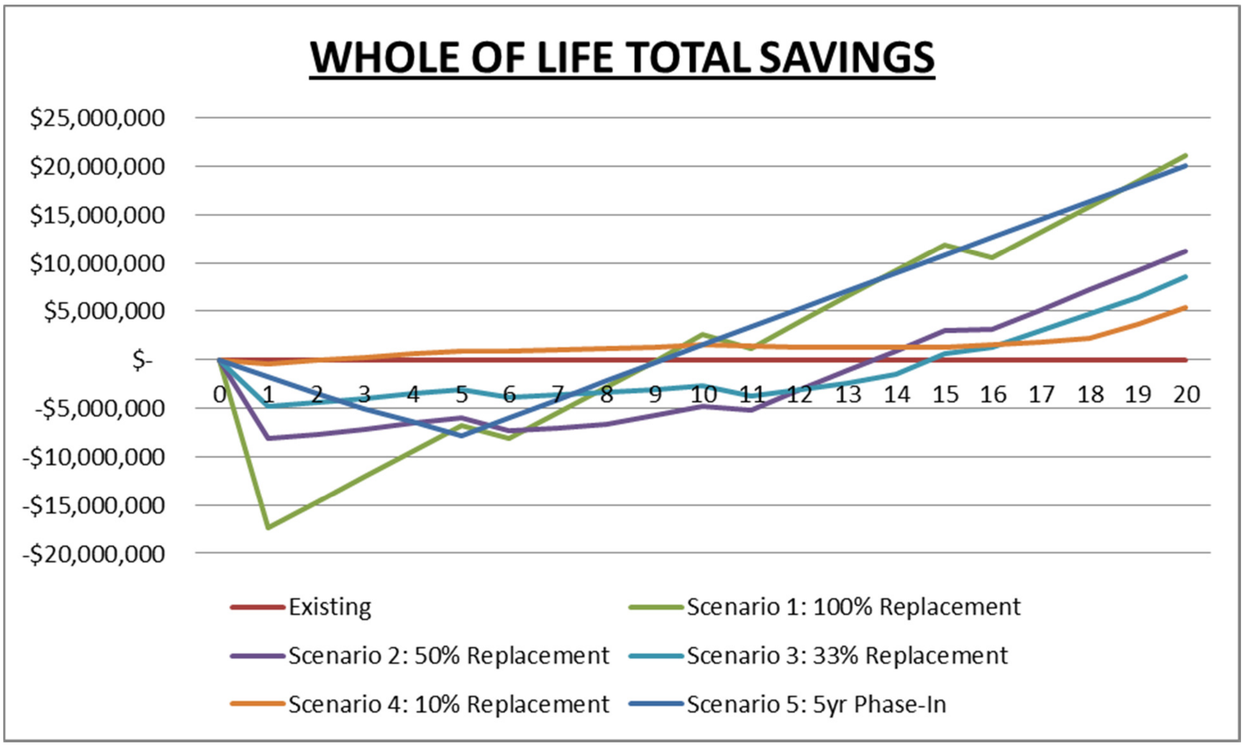

Whole of Life Maintenance Cost: Luminaire Replacement
$35,000,000
$30,000,000
$25,000,000
$20,000,000
$15,000,000
$10,000,000
$5,000,000
$-
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Existing
Scenario 1: 100% Replacement
Scenario 2: 50% Replacement
Scenario 3: 33% Replacement
Scenario 4: 10% Replacement
Scenario 5: 5yr Phase-In

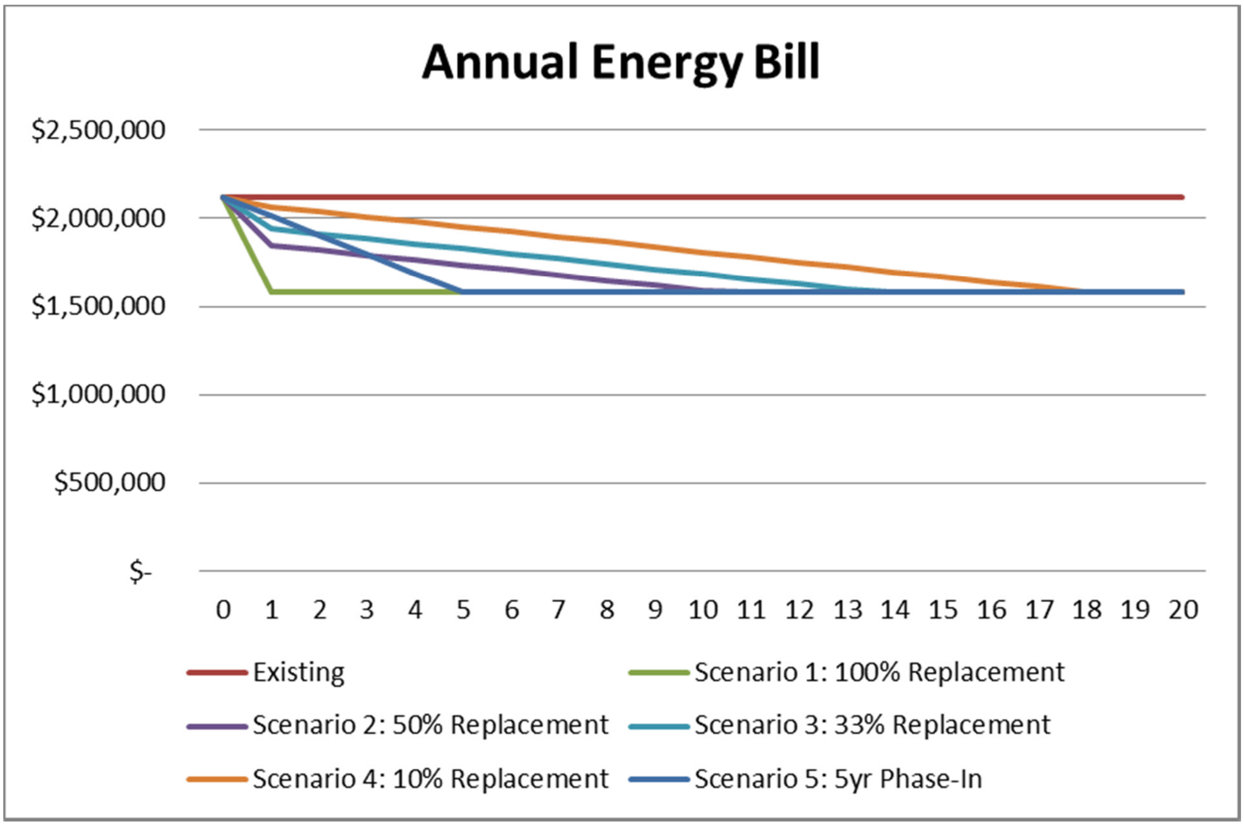

Whole of Life Maintenance Cost: Lamp Replacement & Luminaire Glass Cleaning Visits
$16,000,000
$14,000,000
$12,000,000
$10,000,000
$8,000,000
$6,000,000
$4,000,000
$2,000,000
$-
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Existing
Scenario 1: 100% Replacement
Scenario 2: 50% Replacement
Scenario 3: 33% Replacement
Scenario 4: 10% Replacement
Scenario 5: 5yr Phase-In

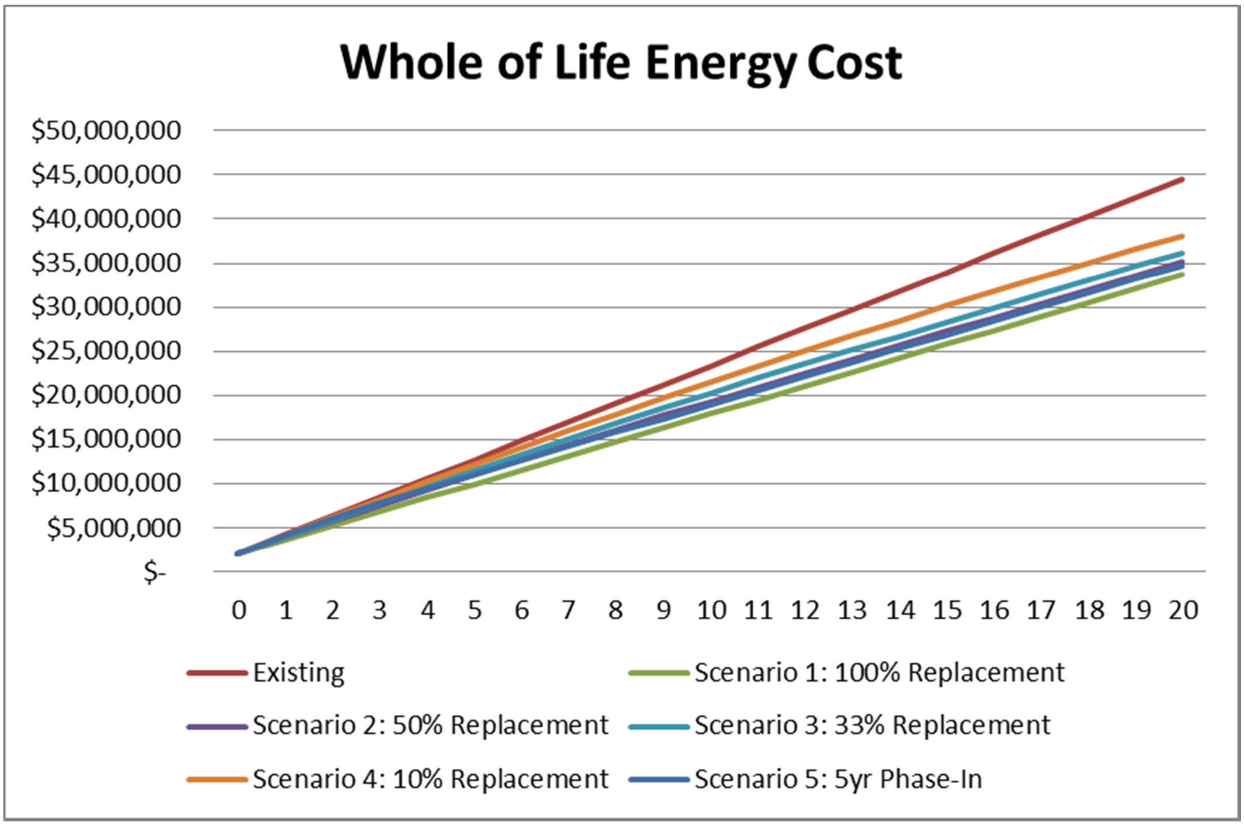

Whole of Life Total Cost
$100,000,000
$90,000,000
$80,000,000
$70,000,000
$60,000,000
$50,000,000
$40,000,000
$30,000,000
$20,000,000
$10,000,000
$-
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Existing
Scenario 1: 100% Replacement
Scenario 2: 50% Replacement
Scenario 3: 33% Replacement
Scenario 4: 10% Replacement
Scenario 5: 5yr Phase-In

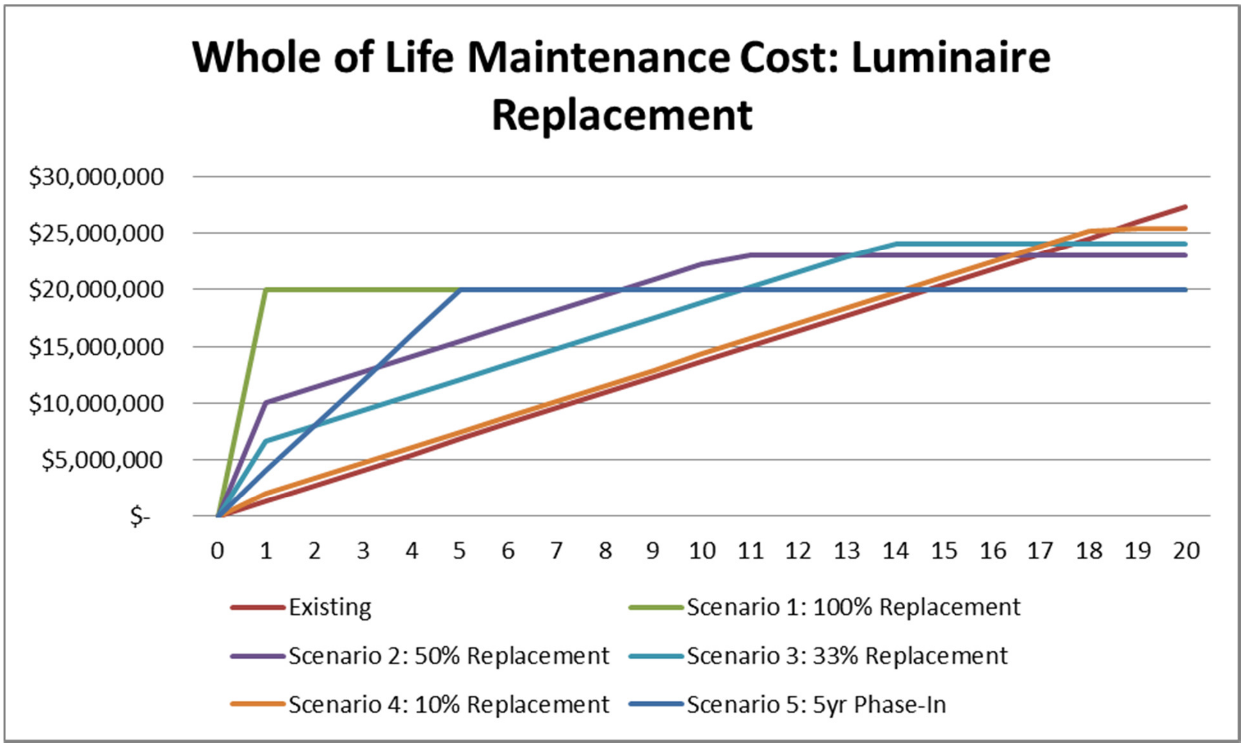
Appendix D – 70W HPS to 50W CMH

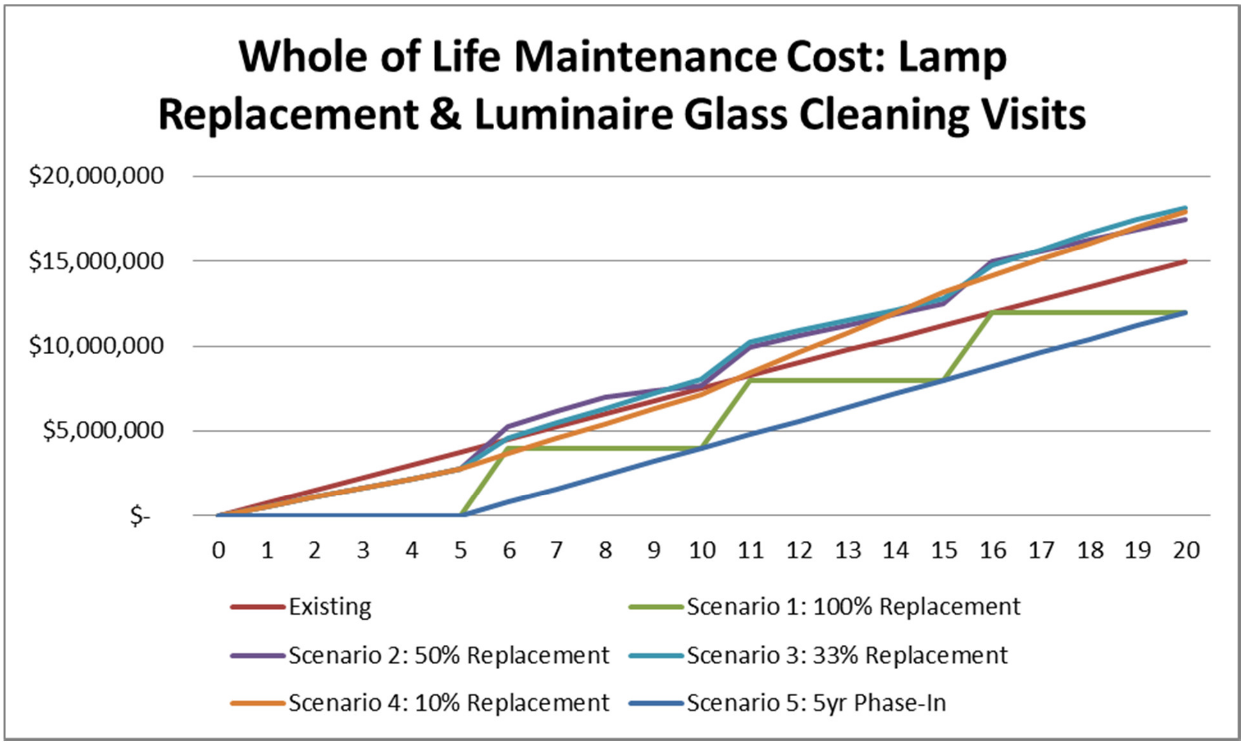
Without Dimming / CLO

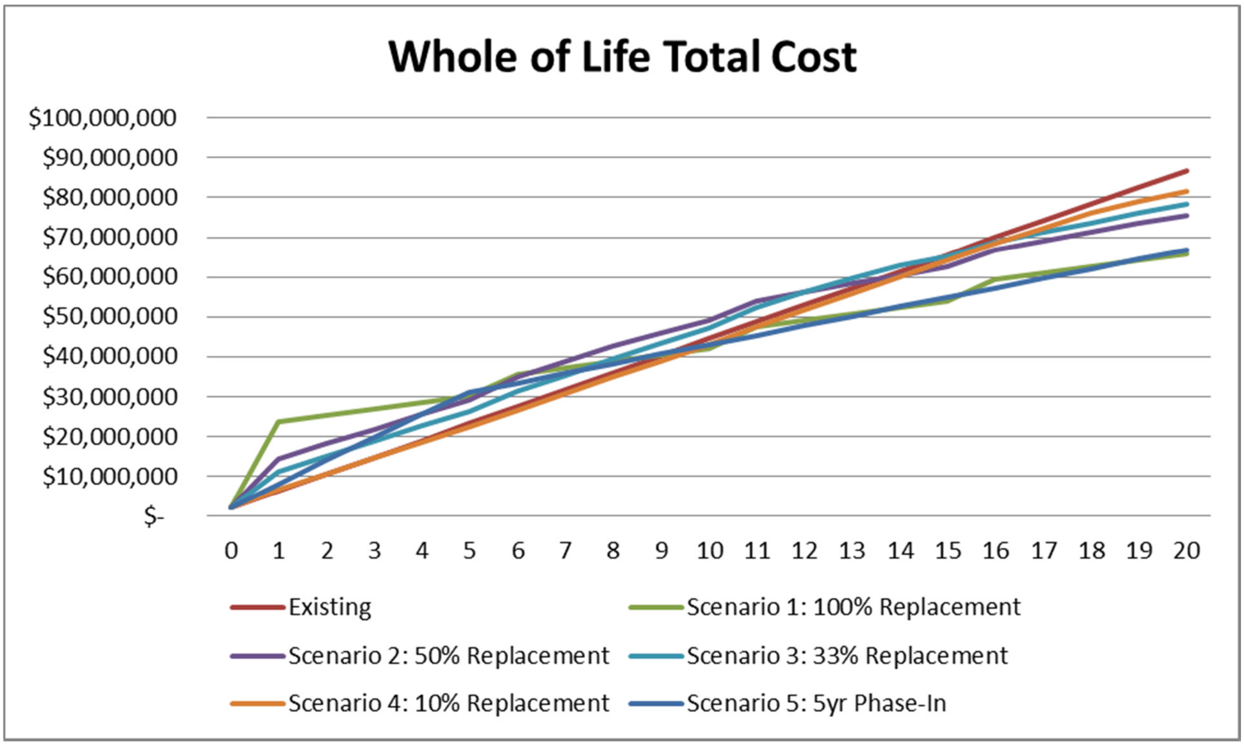




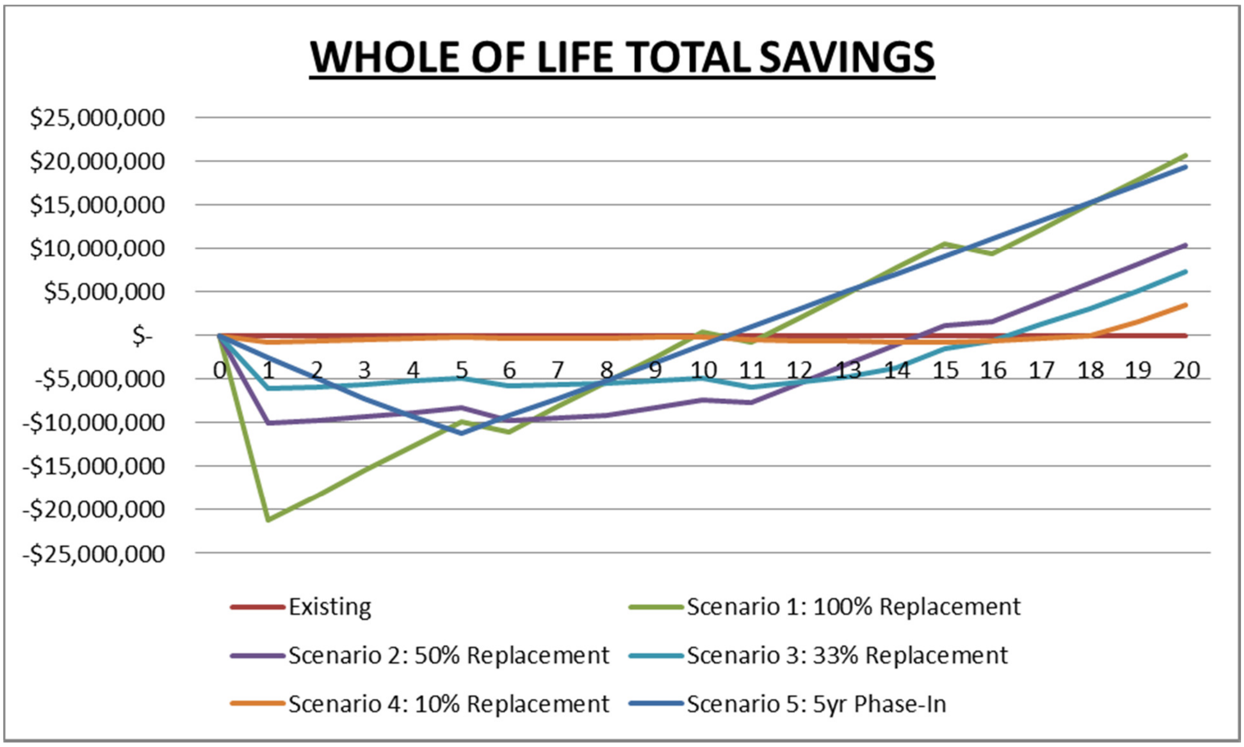

Whole of Life Energy Cost
$50,000,000
$45,000,000
$40,000,000
$35,000,000
$30,000,000
$25,000,000
$20,000,000
$15,000,000
$10,000,000
$5,000,000
$-
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Existing
Scenario 1: 100% Replacement
Scenario 2: 50% Replacement
Scenario 3: 33% Replacement
Scenario 4: 10% Replacement
Scenario 5: 5yr Phase-In

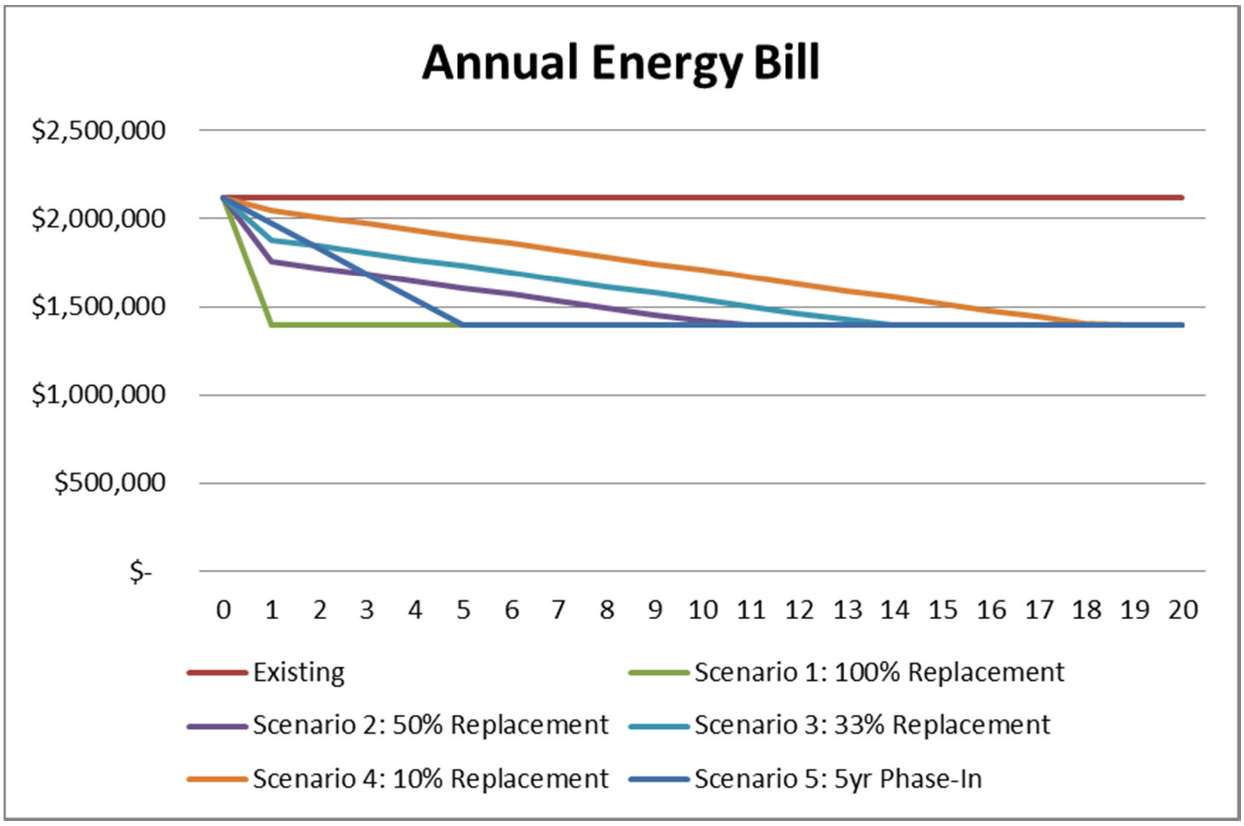

Whole of Life Maintenance Cost: Luminaire Replacement
$30,000,000
$25,000,000
$20,000,000
$15,000,000
$10,000,000
$5,000,000
$-
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Existing
Scenario 1: 100% Replacement
Scenario 2: 50% Replacement
Scenario 3: 33% Replacement
Scenario 4: 10% Replacement
Scenario 5: 5yr Phase-In

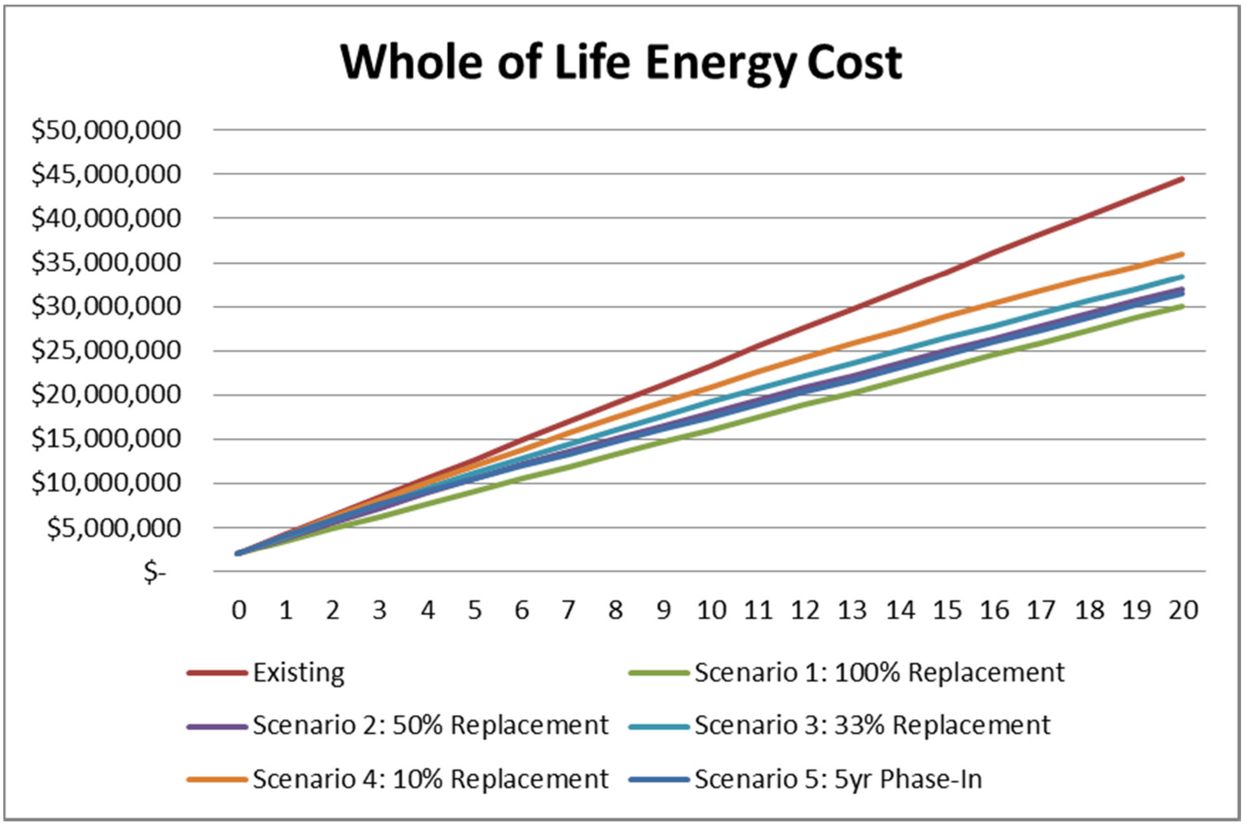

Whole of Life Maintenance Cost: Lamp Replacement & Luminaire Glass Cleaning Visits
$20,000,000
$15,000,000
$10,000,000
$5,000,000
$-
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Existing
Scenario 1: 100% Replacement
Scenario 2: 50% Replacement
Scenario 3: 33% Replacement
Scenario 4: 10% Replacement
Scenario 5: 5yr Phase-In

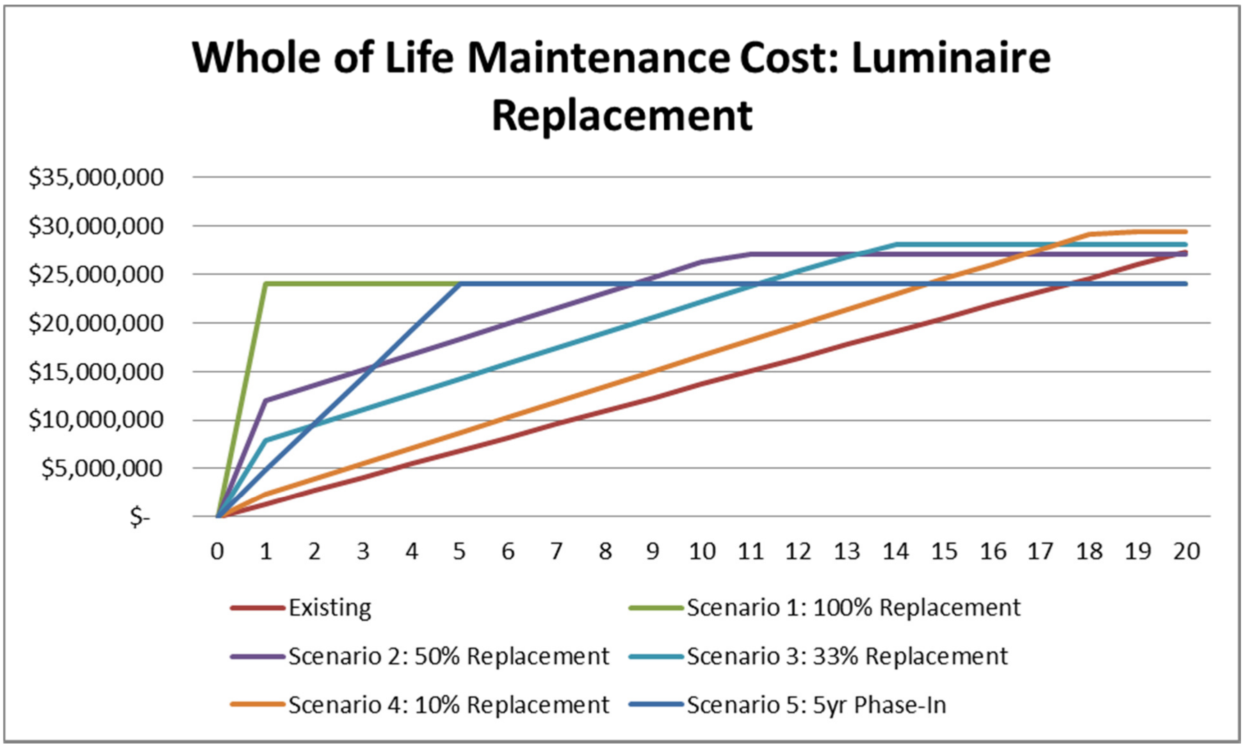

Whole of Life Total Cost
$100,000,000
$90,000,000
$80,000,000
$70,000,000
$60,000,000
$50,000,000
$40,000,000
$30,000,000
$20,000,000
$10,000,000
$-
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Existing
Scenario 1: 100% Replacement
Scenario 2: 50% Replacement
Scenario 3: 33% Replacement
Scenario 4: 10% Replacement
Scenario 5: 5yr Phase-In

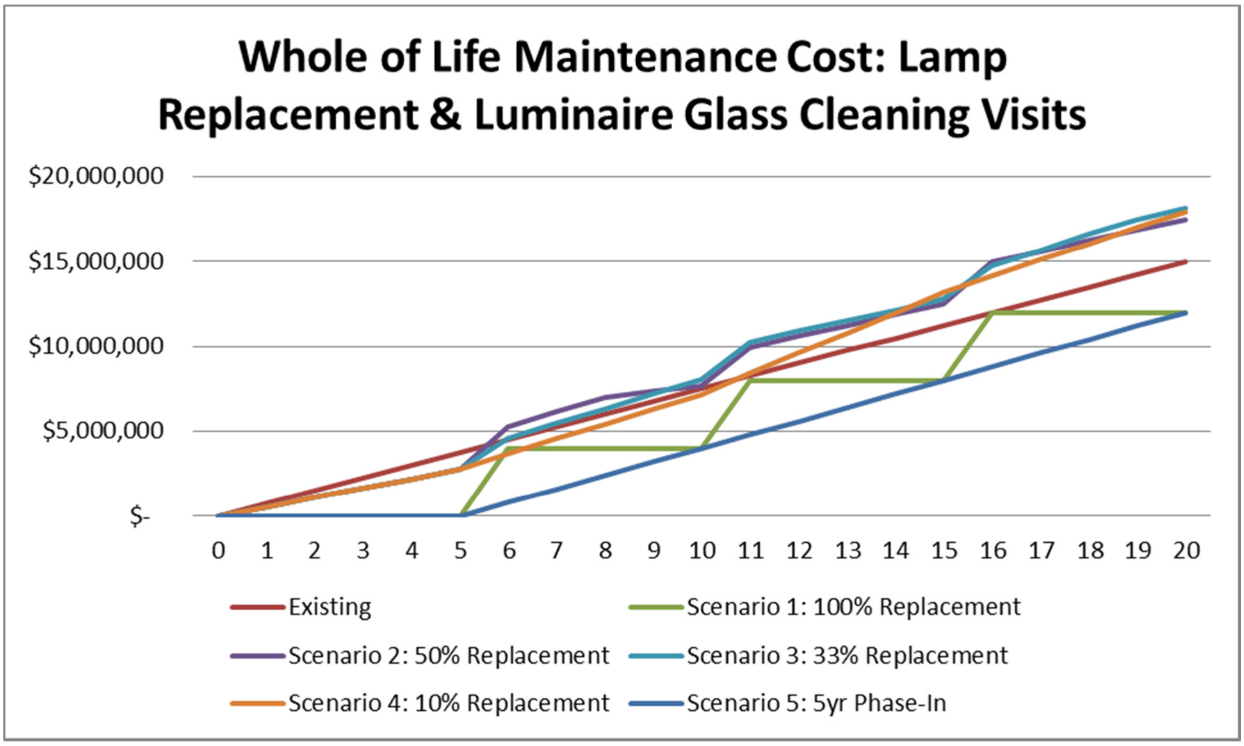
With Dimming / CLO

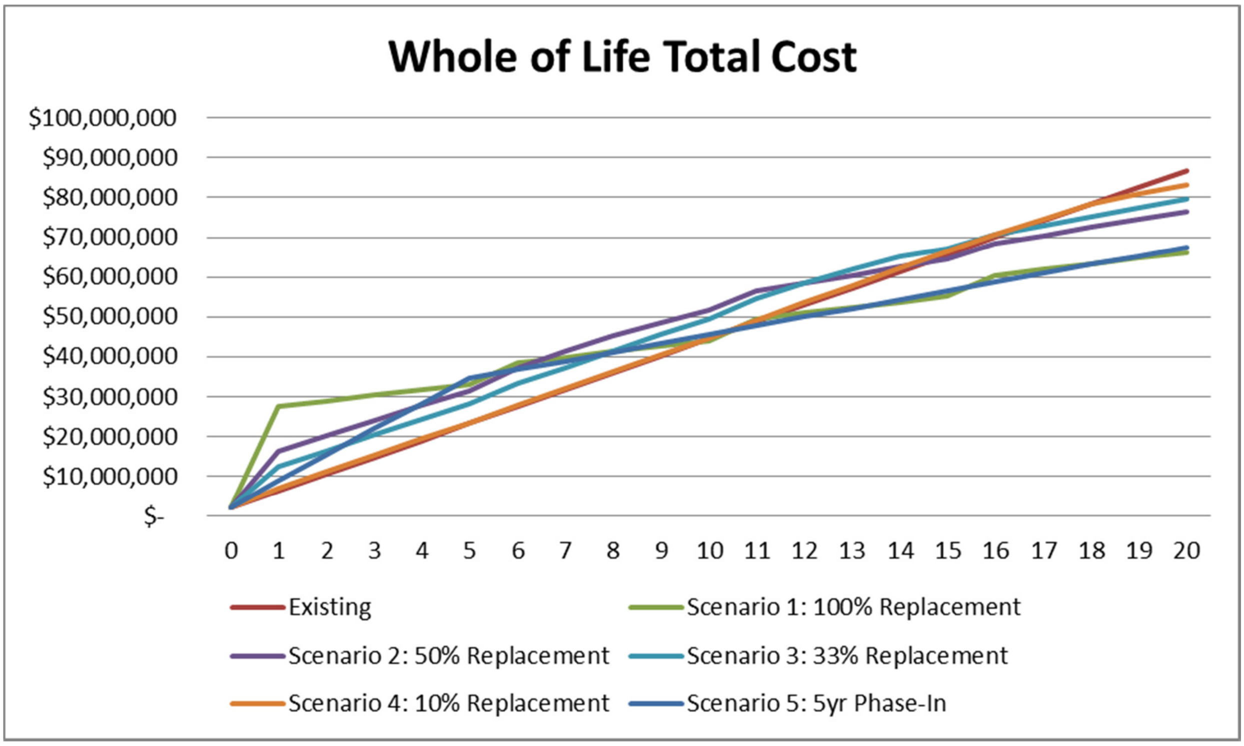





Whole of Life Energy Cost
$50,000,000
$45,000,000
$40,000,000
$35,000,000
$30,000,000
$25,000,000
$20,000,000
$15,000,000
$10,000,000
$5,000,000
$-
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Existing
Scenario 1: 100% Replacement
Scenario 2: 50% Replacement
Scenario 3: 33% Replacement
Scenario 4: 10% Replacement
Scenario 5: 5yr Phase-In

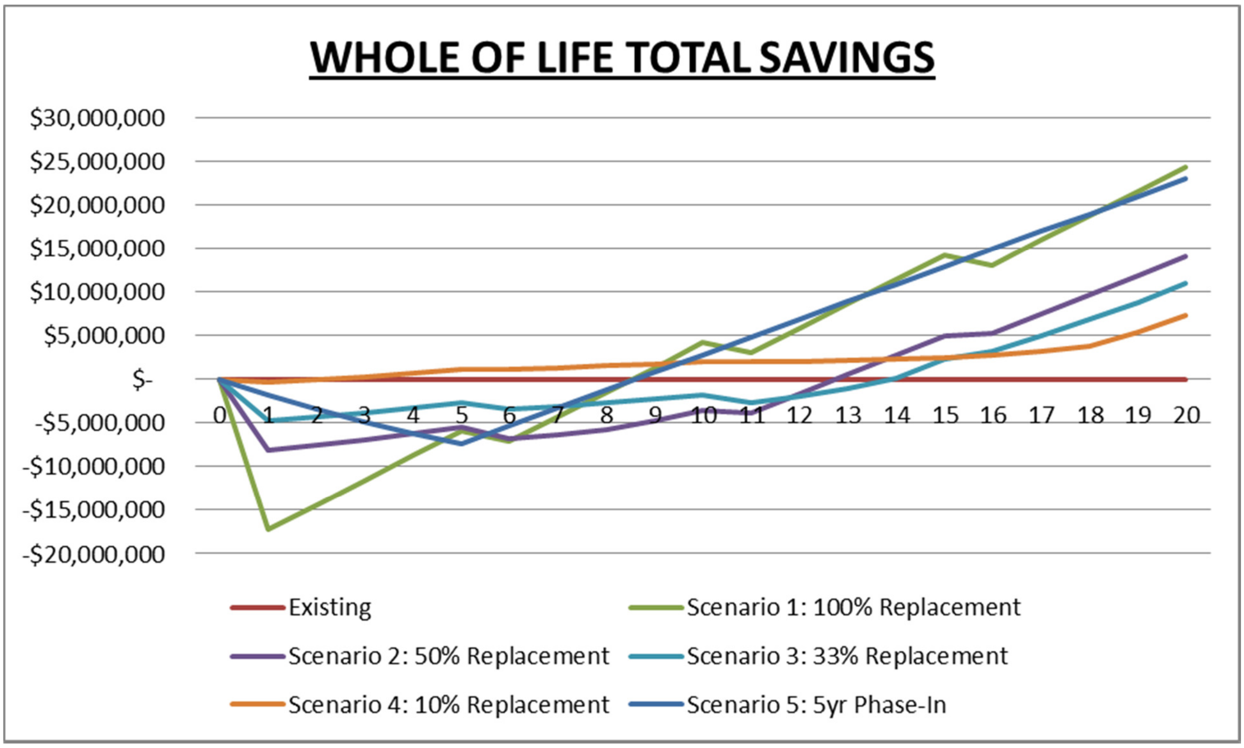

Whole of Life Maintenance Cost: Luminaire Replacement
$35,000,000
$30,000,000
$25,000,000
$20,000,000
$15,000,000
$10,000,000
$5,000,000
$-
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Existing
Scenario 1: 100% Replacement
Scenario 2: 50% Replacement
Scenario 3: 33% Replacement
Scenario 4: 10% Replacement
Scenario 5: 5yr Phase-In

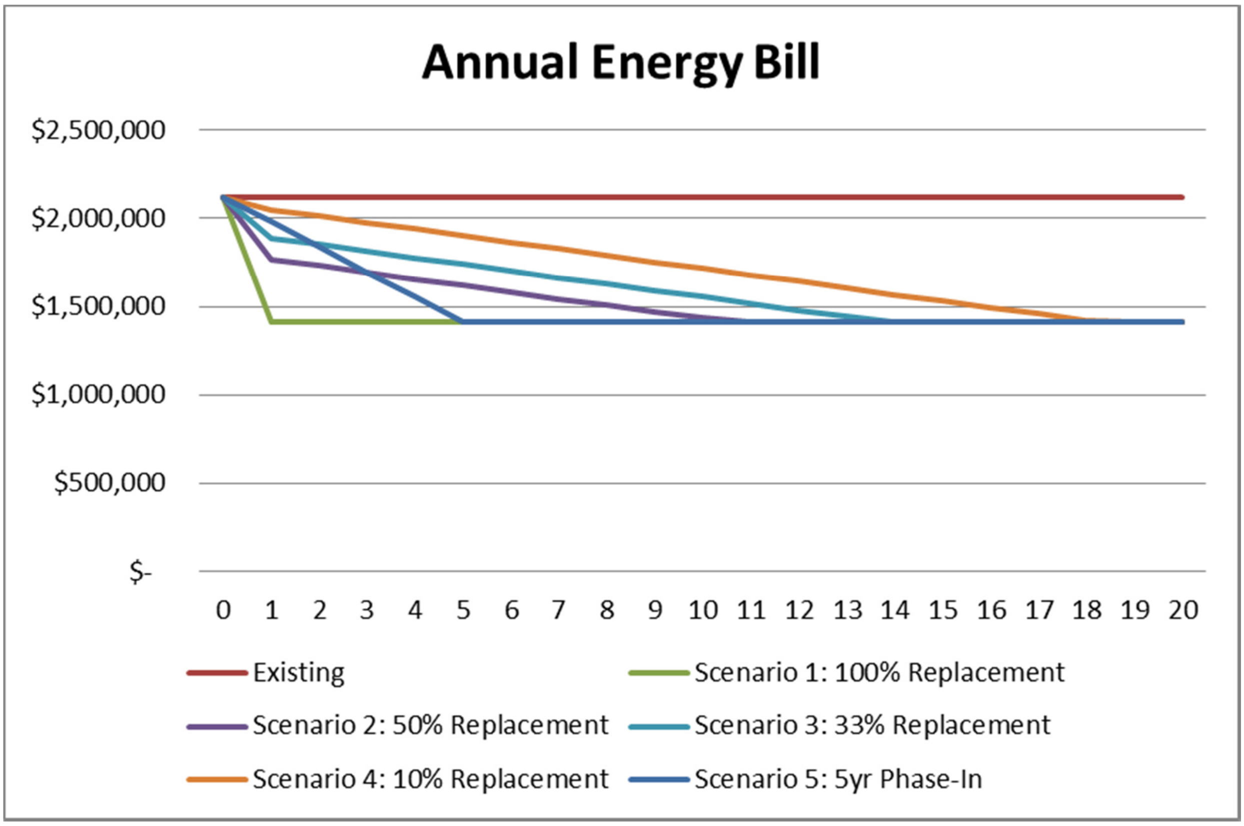

Whole of Life Maintenance Cost: Lamp Replacement & Luminaire Glass Cleaning Visits
$20,000,000
$15,000,000
$10,000,000
$5,000,000
$-
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Existing
Scenario 1: 100% Replacement
Scenario 2: 50% Replacement
Scenario 3: 33% Replacement
Scenario 4: 10% Replacement
Scenario 5: 5yr Phase-In

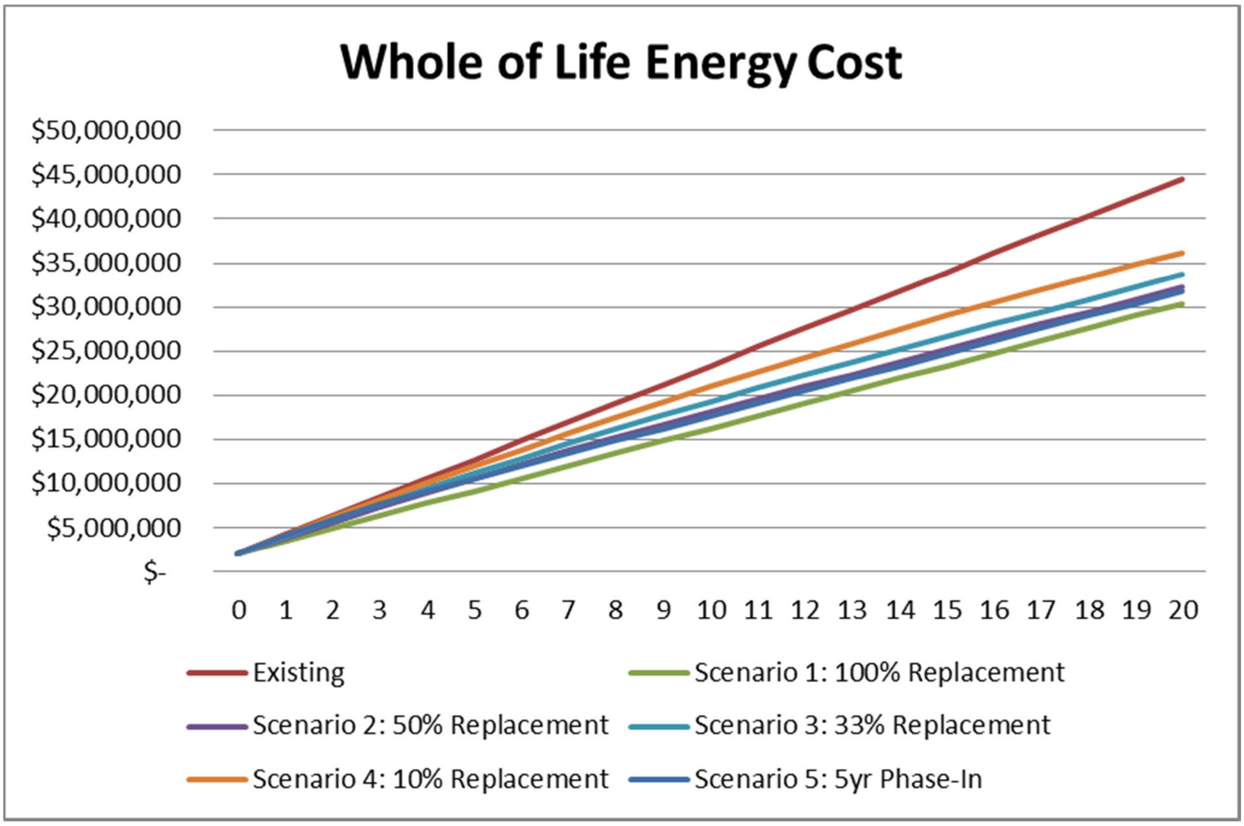

Whole of Life Total Cost
$100,000,000
$90,000,000
$80,000,000
$70,000,000
$60,000,000
$50,000,000
$40,000,000
$30,000,000
$20,000,000
$10,000,000
$-
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Existing
Scenario 1: 100% Replacement
Scenario 2: 50% Replacement
Scenario 3: 33% Replacement
Scenario 4: 10% Replacement
Scenario 5: 5yr Phase-In

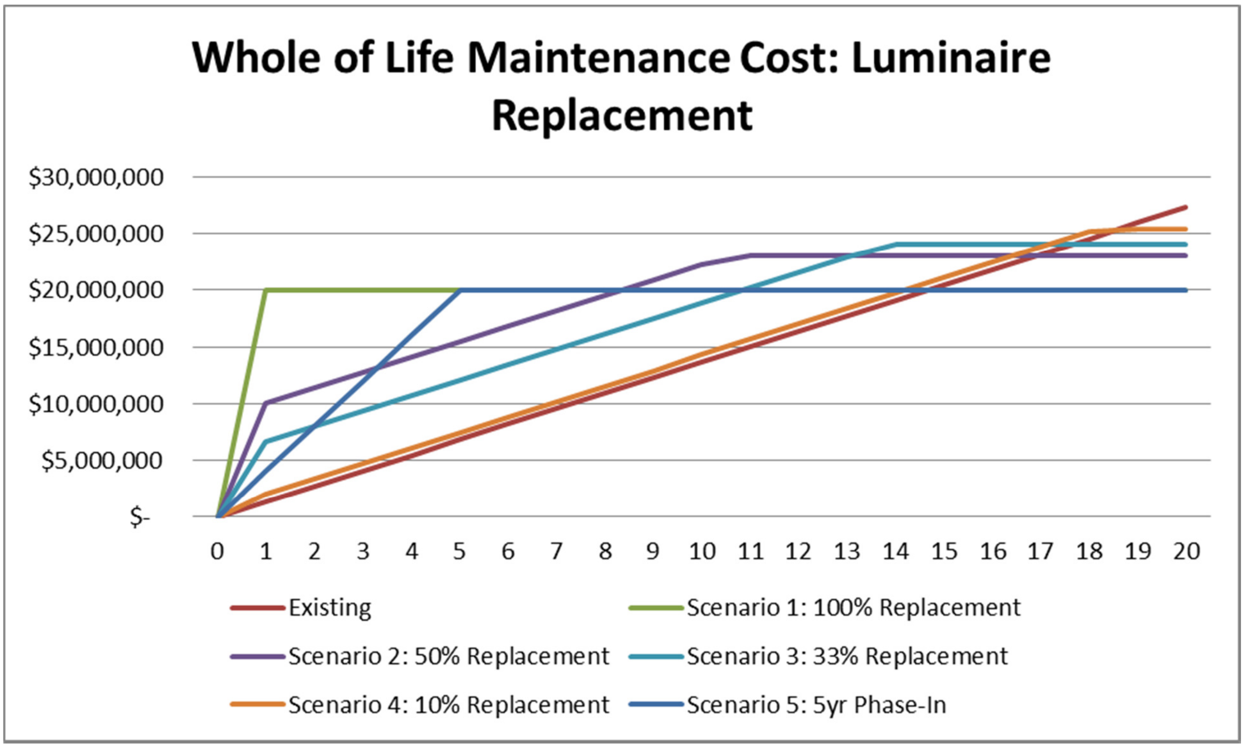
Appendix E – 70W HPS to Cosmopolis

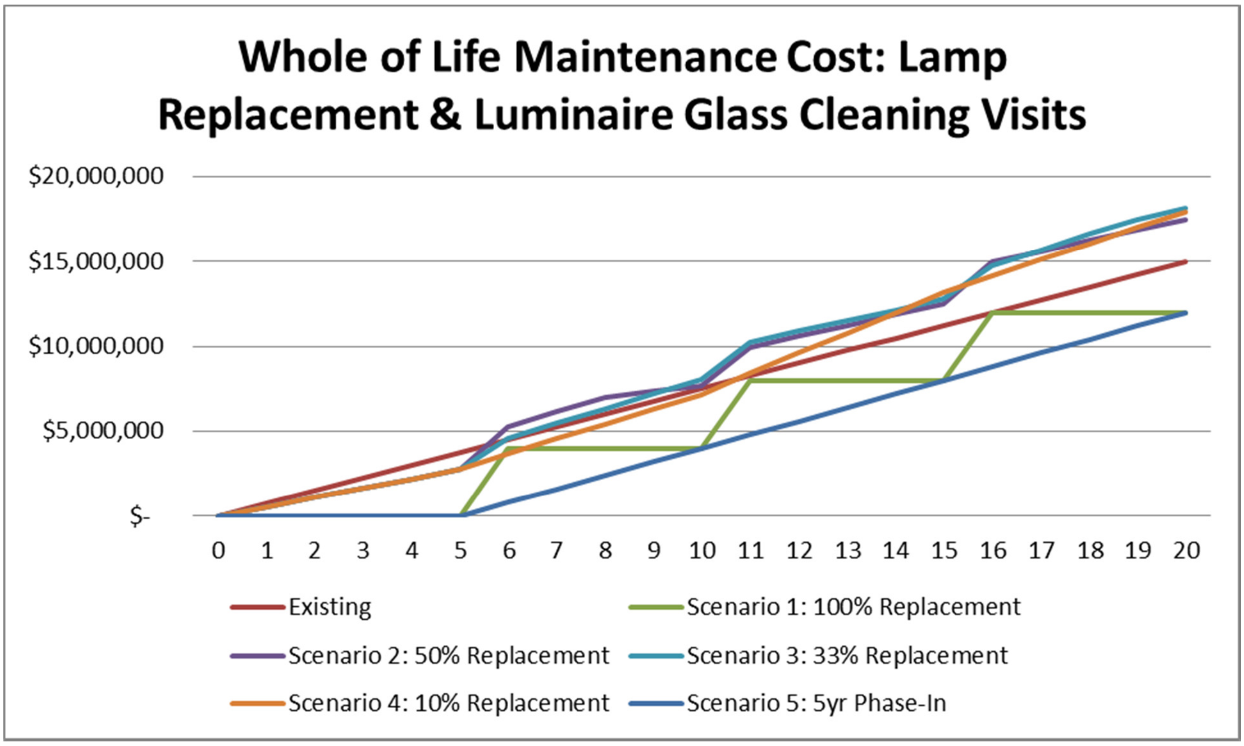
Without Dimming / CLO

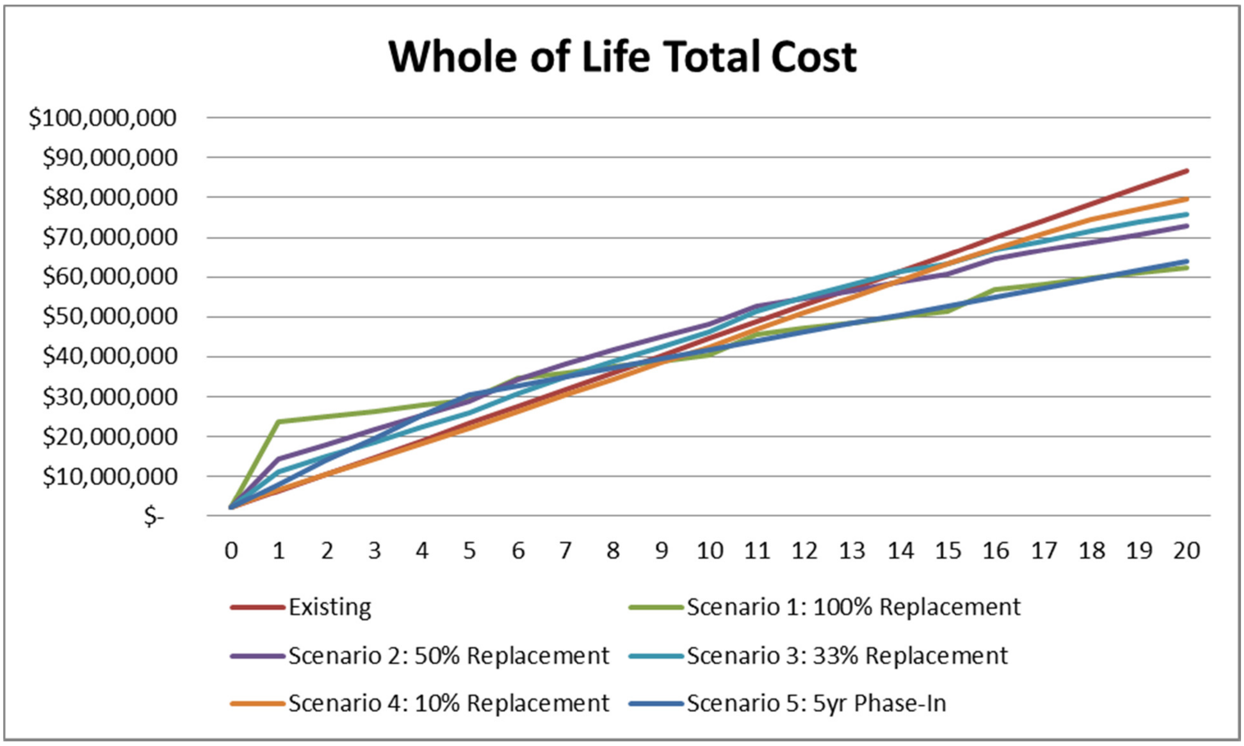




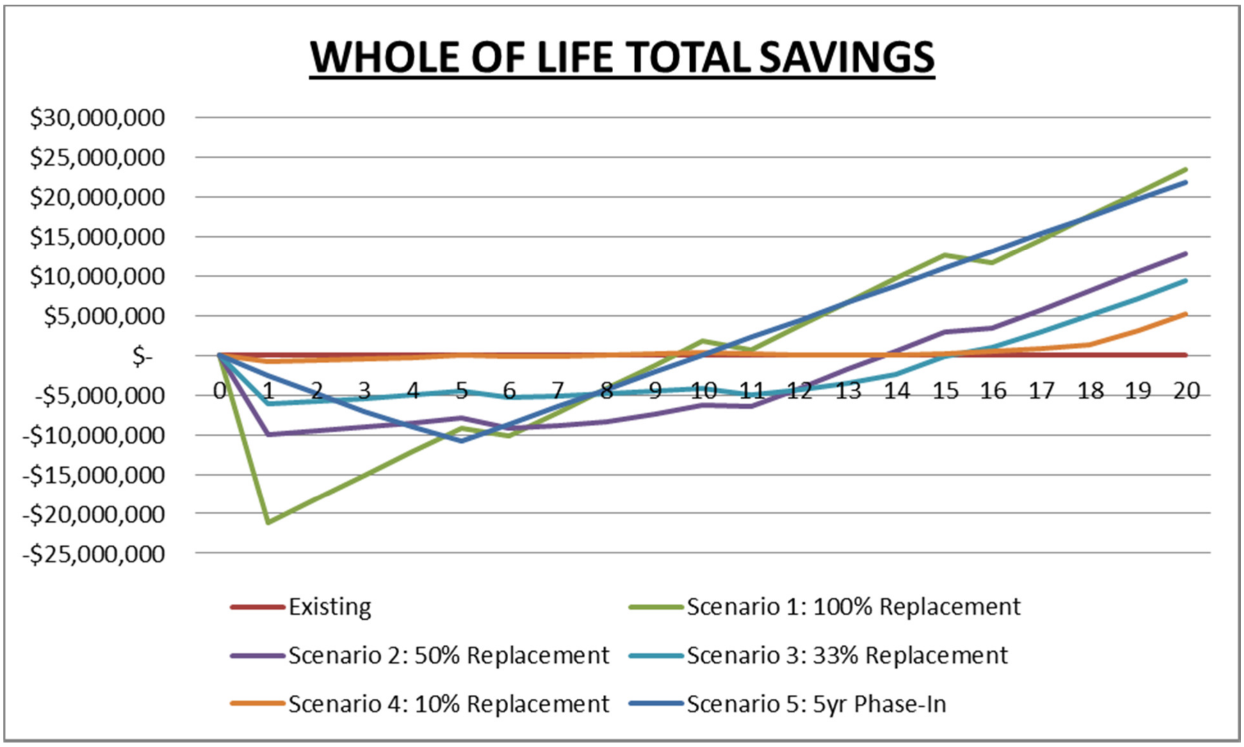

Whole of Life Energy Cost
$50,000,000
$45,000,000
$40,000,000
$35,000,000
$30,000,000
$25,000,000
$20,000,000
$15,000,000
$10,000,000
$5,000,000
$-
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Existing
Scenario 1: 100% Replacement
Scenario 2: 50% Replacement
Scenario 3: 33% Replacement
Scenario 4: 10% Replacement
Scenario 5: 5yr Phase-In

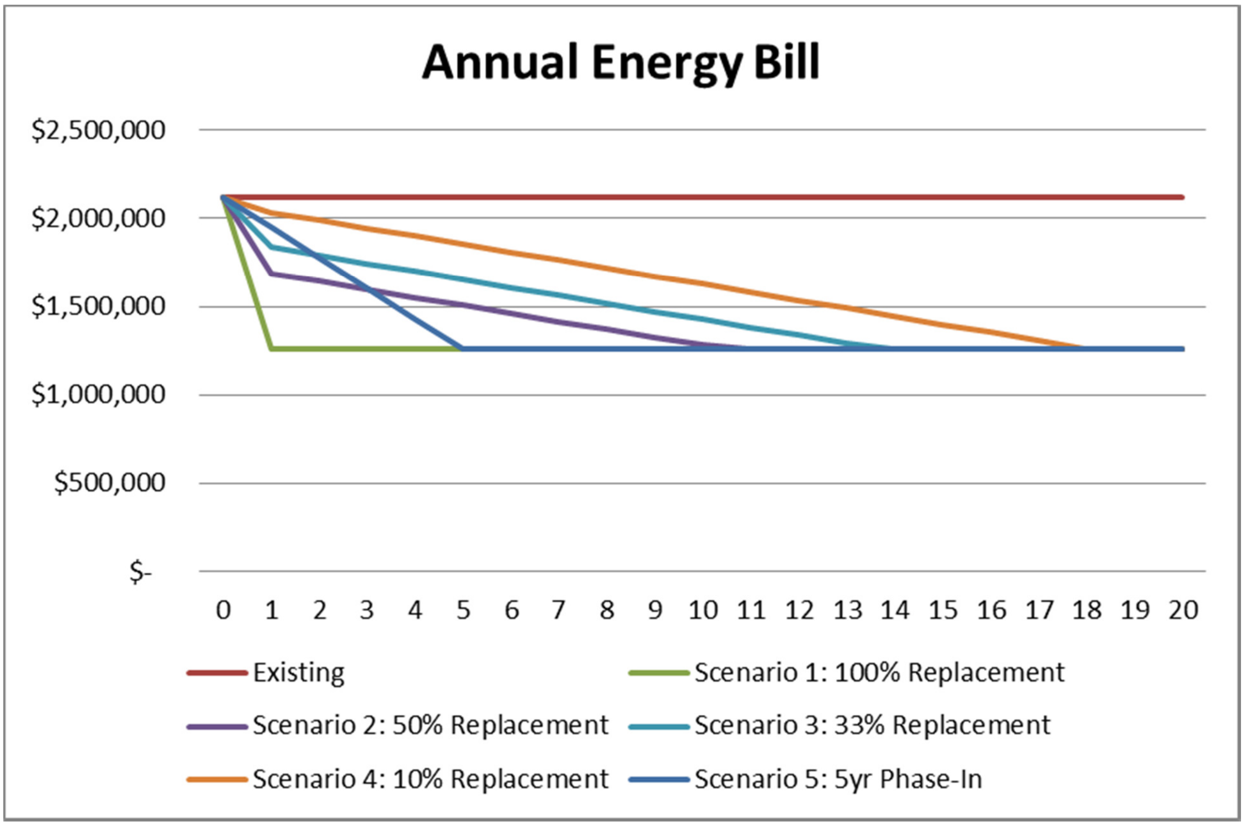

Whole of Life Maintenance Cost: Luminaire Replacement
$30,000,000
$25,000,000
$20,000,000
$15,000,000
$10,000,000
$5,000,000
$-
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Existing
Scenario 1: 100% Replacement
Scenario 2: 50% Replacement
Scenario 3: 33% Replacement
Scenario 4: 10% Replacement
Scenario 5: 5yr Phase-In

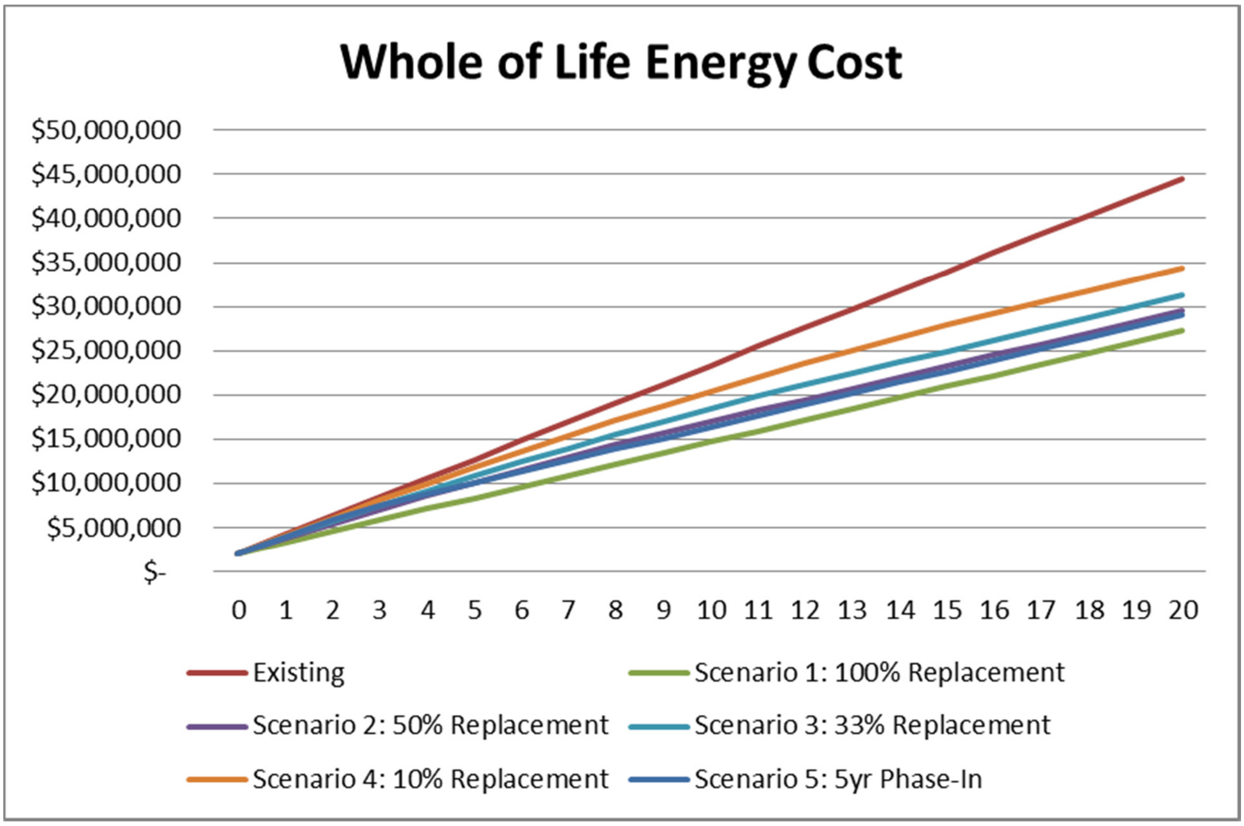

Whole of Life Maintenance Cost: Lamp Replacement & Luminaire Glass Cleaning Visits
$20,000,000
$15,000,000
$10,000,000
$5,000,000
$-
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Existing
Scenario 1: 100% Replacement
Scenario 2: 50% Replacement
Scenario 3: 33% Replacement
Scenario 4: 10% Replacement
Scenario 5: 5yr Phase-In

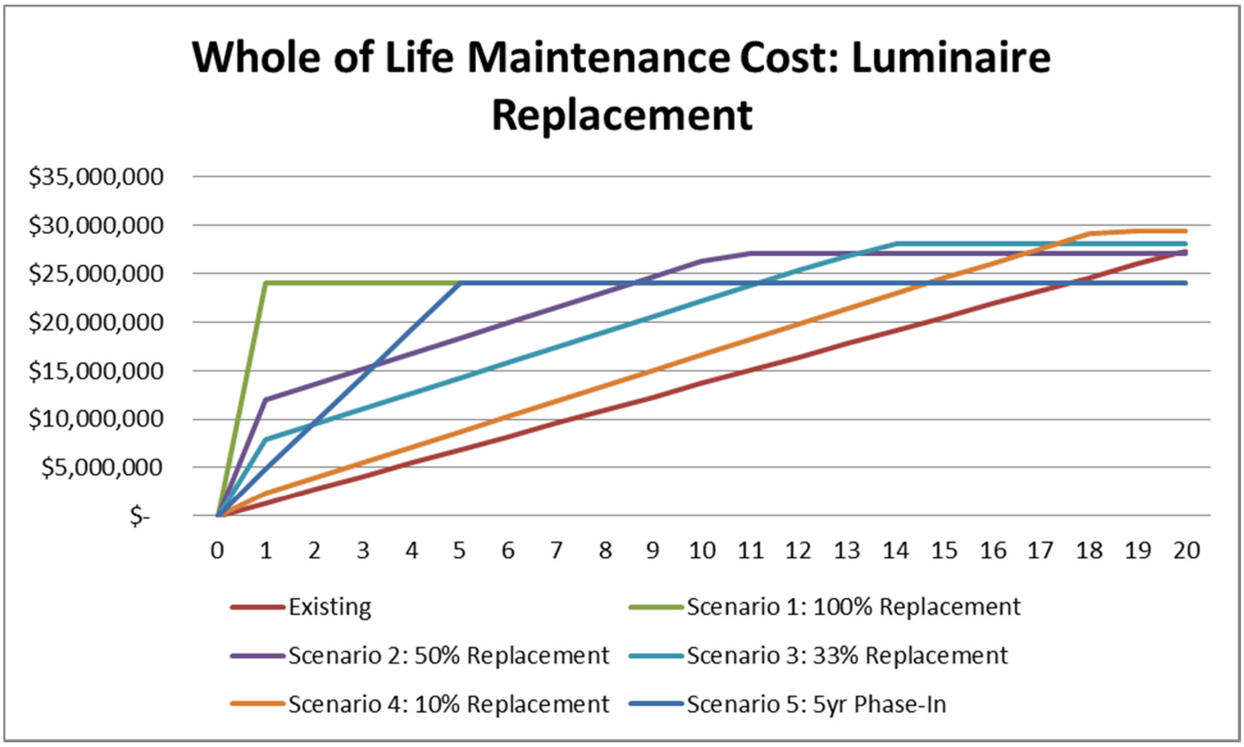

Whole of Life Total Cost
$100,000,000
$90,000,000
$80,000,000
$70,000,000
$60,000,000
$50,000,000
$40,000,000
$30,000,000
$20,000,000
$10,000,000
$-
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Existing
Scenario 1: 100% Replacement
Scenario 2: 50% Replacement
Scenario 3: 33% Replacement
Scenario 4: 10% Replacement
Scenario 5: 5yr Phase-In

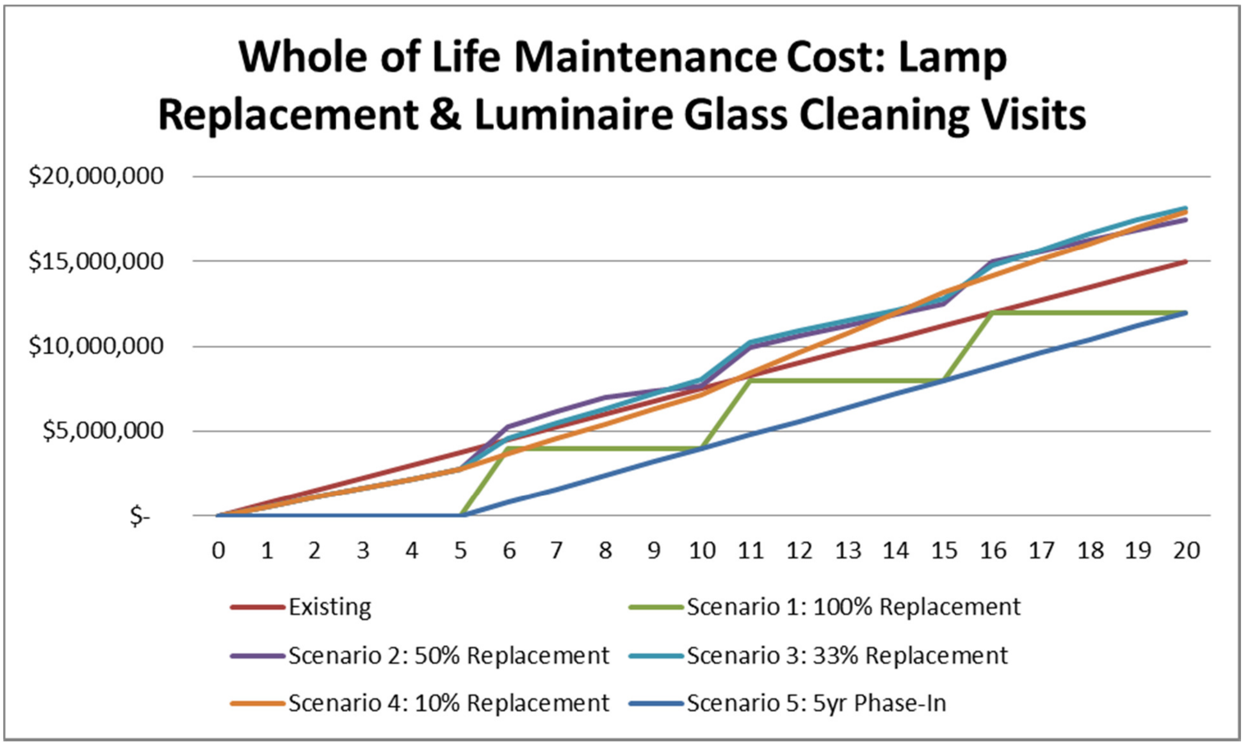
With Dimming / CLO

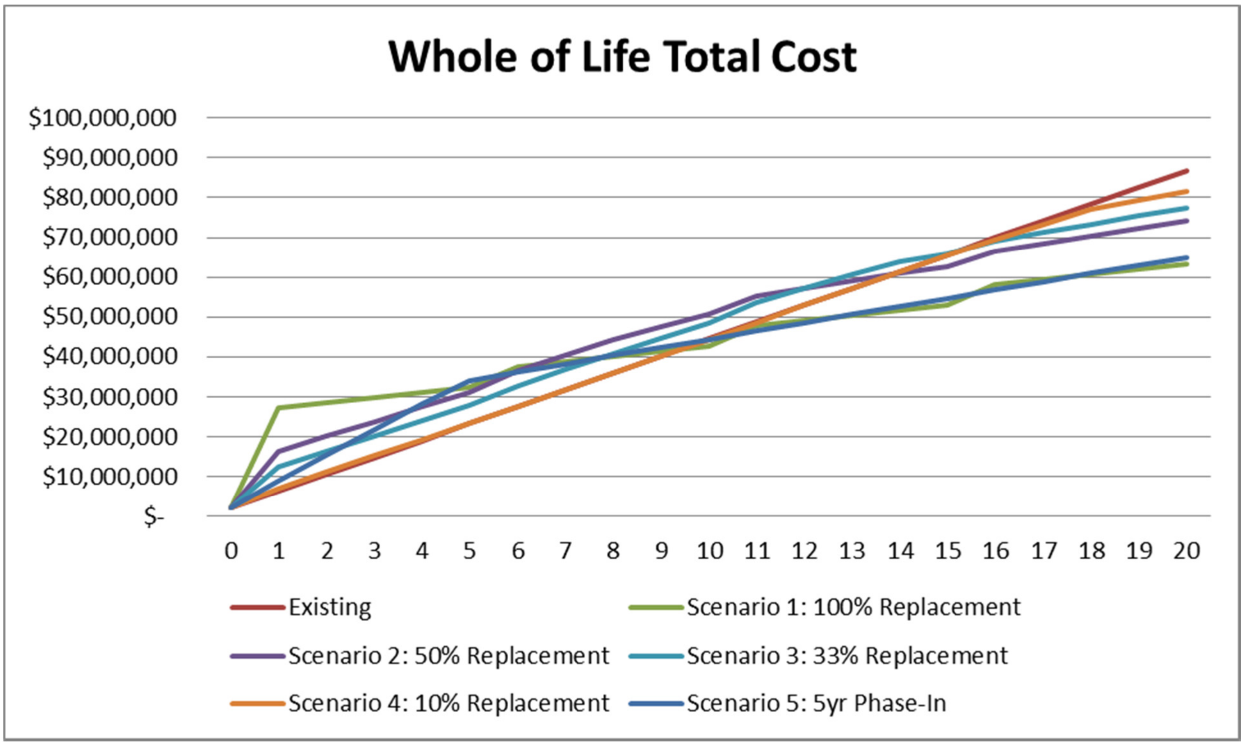





Whole of Life Energy Cost
$50,000,000
$45,000,000
$40,000,000
$35,000,000
$30,000,000
$25,000,000
$20,000,000
$15,000,000
$10,000,000
$5,000,000
$-
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Existing
Scenario 1: 100% Replacement
Scenario 2: 50% Replacement
Scenario 3: 33% Replacement
Scenario 4: 10% Replacement
Scenario 5: 5yr Phase-In


Whole of Life Maintenance Cost: Luminaire Replacement
$35,000,000
$30,000,000
$25,000,000
$20,000,000
$15,000,000
$10,000,000
$5,000,000
$-
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Existing
Scenario 1: 100% Replacement
Scenario 2: 50% Replacement
Scenario 3: 33% Replacement
Scenario 4: 10% Replacement
Scenario 5: 5yr Phase-In


Whole of Life Maintenance Cost: Lamp Replacement & Luminaire Glass Cleaning Visits
$20,000,000
$15,000,000
$10,000,000
$5,000,000
$-
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Existing
Scenario 1: 100% Replacement
Scenario 2: 50% Replacement
Scenario 3: 33% Replacement
Scenario 4: 10% Replacement
Scenario 5: 5yr Phase-In


Whole of Life Total Cost
$100,000,000
$90,000,000
$80,000,000
$70,000,000
$60,000,000
$50,000,000
$40,000,000
$30,000,000
$20,000,000
$10,000,000
$-
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Existing
Scenario 1: 100% Replacement
Scenario 2: 50% Replacement
Scenario 3: 33% Replacement
Scenario 4: 10% Replacement
Scenario 5: 5yr Phase-In