**FTTP Deployment Cost & Financial Projections**

**Prepared for the Holland Board of Public Works March 2016**

**Draft**

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

**Contents** 1 Executive Summary ................................................................................................................. 1

1.1 Background and Objectives .............................................................................................. 1

1.2 Candidate FTTP Design ..................................................................................................... 1

1.3 Financial Overview ........................................................................................................... 3

1.4 Recommendations ........................................................................................................... 5

2 Assessment of Local Broadband Market ................................................................................ 7

2.1 Residential and Small Business Services .......................................................................... 7

2.1.1 Cable ......................................................................................................................... 7

2.1.2 DSL........................................................................................................................... 11

2.1.3 HBPW Fiber ............................................................................................................. 12

2.1.4 Satellite ................................................................................................................... 12

2.1.5 Wireless ................................................................................................................... 13

2.2 Enterprise Market .......................................................................................................... 14

2.2.1 Dark Fiber Services .................................................................................................. 15

2.2.2 Lit Services .............................................................................................................. 15

3 FTTP Objectives ..................................................................................................................... 19

3.1 Common Community Broadband Objectives ................................................................ 19

3.2 Ubiquity .......................................................................................................................... 21

3.3 Consumer Choice ........................................................................................................... 23

3.4 Competition in the Market ............................................................................................. 24

3.5 Ownership and Control of Assets ................................................................................... 25

3.6 Performance ................................................................................................................... 26

3.7 Affordability .................................................................................................................... 27

3.8 Risk Aversion .................................................................................................................. 28

3.9 Cash Flow ....................................................................................................................... 30

4 FTTP Network Requirements ................................................................................................ 32

4.1 User Applications and Services ...................................................................................... 32

4.1.1 Internet Access........................................................................................................ 32

ii

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

4.1.2 IP Telephony (VoIP) and Video Conferencing ......................................................... 33

4.1.3 Streaming Video ...................................................................................................... 33

4.1.4 Cloud Access ........................................................................................................... 34

4.1.5 Over-the-Top (OTT) Programming .......................................................................... 35

4.2 Network Design Considerations ..................................................................................... 37

4.2.1 Why Fiber Optics ..................................................................................................... 37

4.2.2 Fiber Routes and Network Topology ...................................................................... 38

4.2.3 Passive Optical Network—Specifications and Technology Roadmap .................... 39

4.2.4 Managing Network Demand ................................................................................... 41

4.2.5 Internet Protocol (IP) Based Applications ............................................................... 44

4.2.6 Migration from IPv4 to IPv6 Protocol ..................................................................... 44

4.2.7 Multicasting—IP Transport of Video Channels ....................................................... 45

4.3 Target User Groups ........................................................................................................ 47

4.3.1 Residents ................................................................................................................. 47

4.3.2 Small Businesses and Enterprise Users ................................................................... 47

5 FTTP Backbone Conceptual Design and Cost Estimates ....................................................... 49

5.1 FTTP Network Design ..................................................................................................... 49

5.1.1 Design Overview and Key Metrics .......................................................................... 50

5.1.2 Backbone and Primary Hub Sites ............................................................................ 54

5.1.3 Access Network Hubs and Electronics .................................................................... 57

5.1.4 Customer Premises Equipment (CPE) and Service Drops ....................................... 61

5.2 FTTP Network Cost Estimates and Phasing .................................................................... 61

5.2.1 OSP Cost Estimation Methodology and Assumptions ............................................ 64

5.2.2 Fiber Construction Cost Estimates .......................................................................... 67

5.2.3 Network Electronics Cost Estimates ....................................................................... 70

5.2.4 Network Maintenance Costs .................................................................................. 71

5.2.5 Implementation Phasing Considerations ................................................................ 71

6 Financial Projections ............................................................................................................. 75

6.1 Financing Costs and Operating Expenses ....................................................................... 76

iii

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

6.2 Operating and Maintenance Expenses .......................................................................... 81

6.3 Summary of Operating and Maintenance Assumptions ................................................ 82

6.4 Sensitivity Scenarios ....................................................................................................... 83

6.4.1 Adding Upfront or Annual Fees Would Reduce the Required Take Rate ............... 83

6.4.2 Adding Funding to Decrease Borrowing Would Lower Required Take Rate .......... 84

6.4.3 Reducing or Increasing Staffing Levels and Costs Changes Required Take Rates .. 87

6.4.4 Decreasing Pricing Affects the Required Take Rate or the Total Cash Balance ..... 89

6.4.5 Impact of Wholesale Service Levels ........................................................................ 89

6.4.6 Funding Capital Additions with a Special Assessment ............................................ 90

6.4.7 Public-Private Partnership – Shared Risk and Investment ..................................... 91

Appendix A: Review of Potential Alternative FTTP Business Models ........................................... 93

Retail Data-Only ........................................................................................................................ 93

Retail Data and Voice Example ............................................................................................. 94

Open Access Models ................................................................................................................. 96

Open Access, Data-Only ........................................................................................................ 96

Open Access to Support Data, Voice, and Video .................................................................. 96

Public-Private Partnership Models ........................................................................................... 97

Model 1: Public Investment with Private Partners ............................................................... 97

Model 2: Public Sector Incenting Private Investment .......................................................... 99

Model 3: Shared Investment and Risk ................................................................................ 102

Appendix B: Over-the-Top Providers and Next-Generation Applications .................................. 106

Appendix C: Financial Model ...................................................................................................... 110

Attachment 1: Physical Fiber Topology ...................................................................................... 111

Attachment 2: Logical FTTP Network Architecture .................................................................... 112

Attachment 3: FTTP Backbone Proposed Fiber Routes .............................................................. 113

Attachment 4: OSP Cost Estimate Breakdowns (39.6 Percent Take Rate) ................................. 114

Attachment 5: Candidate Network Equipment BOM ................................................................. 115

Attachment 6: FTTP Cost Model Area Delineations ................................................................... 118

iv

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

**Figures** Figure 1: High-Level FTTP Architecture ........................................................................................... 2 Figure 2: Comcast Service Area ...................................................................................................... 8 Figure 3: Zayo Fiber Routes .......................................................................................................... 15 Figure 4 Windstream Fiber Network ............................................................................................ 18 Figure 5: Interactions between Objectives ................................................................................... 21 Figure 6: Ubiquity Alignments, Conflicts, and Potential Outcomes ............................................. 23 Figure 7: Risk and Reward Matrix ................................................................................................. 29 Figure 8: Unicast IP Network Carries Multiple Copies of Single Video Channel ........................... 46 Figure 9: Multicast IP Network Carries Single Copy of Single Video Channel .............................. 46 Figure 10: FTTP Network Backbone .............................................................................................. 51 Figure 11: High-Level FTTP Architecture ....................................................................................... 53 Figure 12: Sample Hub Facility ...................................................................................................... 56 Figure 13: Active FDC Example (Calix OD-2000) ........................................................................... 58 Figure 14: Estimated FTTP Costs Are Take Rate-Dependent ........................................................ 64 Figure 15: Sample FTTP Distribution Layer Design ....................................................................... 66 Figure 16: Impact of Initial Funding on Required Take Rate ........................................................ 85

**Tables** Table 1: Summary of Design Model Metrics ................................................................................... 3 Table 2: Base Case Financial Analysis with 39.6 Percent Take Rate ............................................... 4 Table 3: Overview of Residential and Small Business Data Services in Holland ............................. 7 Table 4: Comcast Residential Internet—Internet Only................................................................... 9 Table 5: Comcast Small Business Internet—Internet Only ........................................................... 10 Table 6: AT&T Residential Internet—Internet Only...................................................................... 11 Table 7: AT&T Business Internet—Internet Only ......................................................................... 11 Table 8: Common Goal Alignment ................................................................................................ 20 Table 9: PON Standards ................................................................................................................ 40 Table 10: Summary of Design Model Metrics ............................................................................... 54 Table 11: Estimated FTTP Deployment Costs (Assuming a 39.6 Percent Take Rate) ................... 63 Table 12: FTTP OSP Construction Cost Estimates ......................................................................... 68 Table 13: FTTP Network Electronics Cost Estimate ...................................................................... 70 Table 14: Estimated FTTP Deployment Costs Within City of Holland Boundaries (Assuming a 39.6 Percent Take Rate) ........................................................................................................................ 73 Table 15: Base Case Financial Analysis with 39.6 Percent Take Rate ........................................... 76 Table 16: Operating Expenses in Years 1, 5, 10, 15, and 20 ......................................................... 78

v

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

Table 17: Income Statement ......................................................................................................... 79 Table 18: Cash Flow Statement .................................................................................................... 80 Table 19: Capital Additions ........................................................................................................... 81 Table 20: Labor Expenses .............................................................................................................. 82 Table 21: Adding $125,000 Annual Utility Fee Reduces Required Take Rate to 38.9 Percent .... 84 Table 22: Adding Special Assessments Reduces Required Take Rate to 27 Percent ................... 84 Table 23: Adding $5 Million in Funding and Decreasing Borrowing Reduces Required Take Rate to 37.8 Percent .................................................................................................................................. 85 Table 24: Adding $10 Million in Funding and Decreasing Borrowing Reduces Required Take Rate to 36 Percent ................................................................................................................................. 86 Table 25: Adding $15 Million in Funding and Decreasing Borrowing Reduces Required Take Rate to 33.3 Percent .............................................................................................................................. 86 Table 26: Adding $20 Million in Funding and Decreasing Borrowing Reduces Required Take Rate to 31.5 Percent .............................................................................................................................. 86 Table 27: Reducing Staffing Costs by 20 Percent Reduces Required Take Rate to 38.3 Percent . 87 Table 28: Increasing Staffing Costs by 20 Percent Increases Required Take Rate to 41.4 Percent ....................................................................................................................................................... 87 Table 29: Increasing Customer Service Representative Shifts (from 1.5 to 3), Eliminating Contracted After-Hours Support .................................................................................................. 88 Table 30: Reducing Customer Service Representative and Technician Shifts by Two Staff Each 88 Table 31: Reducing Customer Service Representative and Technician Shifts by Two Staff Each and Reducing Take Rate to 38.3 Percent ............................................................................................. 88 Table 32: Decreasing Pricing by 10 Percent Increases Required Take Rate to 45.9 Percent ....... 89 Table 33: Decreasing Pricing by 10 Percent with Same Take Rate Lowers Total Cash Balance ... 89 Table 34: Wholesale ISPs Serve 50 Percent of Subscribers, HBPW Reduces Staffing .................. 90 Table 35: Wholesale ISPs Serve 10 Percent of Subscribers at Reduced Wholesale Rates ........... 90 Table 36: Use of Special Assessment Reduces Retail Pricing by 40 Percent ................................ 91 Table 37: Dark Fiber Lease Example – Public–Private Partnership .............................................. 92

vi

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

**1 Executive Summary**

**1.1 Background and Objectives** The Holland Board of Public Works (HBPW) owns and operates a fiber optic network that includes infrastructure throughout parts of its service area, encompassing the City of Holland and surrounding communities. The HBPW currently serves commercial customers over fiber with three different service offerings: dark fiber leases, point-to-point bandwidth direct to customers, and “open access” bandwidth for Internet Service Providers (ISP) to sell services to customers.

The HBPW is interested in potentially expanding its successful fiber operation in two ways: First, using its existing fiber as a foundation, it seeks to deploy an expanded fiber-to-the-premises (FTTP) network throughout its service area to reach more customers. Second, it seeks to act as an ISP and sell services directly to customers—while also maintaining its open access approach, and promoting competition in the local broadband market by continuing to lower the barriers to entry for competitive ISPs.

Through this planned expansion, the HBPW seeks to increase the availability and affordability of 1 Gbps (“gigabit”) service—and, in the long term, to future-proof its network so that it will continue to meet the community’s broadband needs.

The HBPW hired CTC Technology & Energy (CTC) to evaluate the HBPW’s existing infrastructure, analyze various financial models for an FTTP expansion, and develop a cost estimate for outside plant (OSP) construction.

**1.2 Candidate FTTP Design** The recommended design is a hierarchical data network with different attributes at each layer, targeting a balance of critical scalability and flexibility, both in terms of the initial network deployment and the network’s capability to accommodate the increased demands of future applications and technologies. The design criteria driving this hierarchical FTTP data network are capacity, availability, physical path diversity, scalability, flexibility, and security.

Extensively leveraging the existing HBPW fiber plant, the recommended design entails a backbone network interconnecting approximately 24 hub locations over approximately 45 miles of physically diverse routes. The backbone includes core network electronics of sufficient capacity and scalability to support the demands of residential and business FTTP services throughout the HBPW electric service footprint. The backbone design seeks to deliver high- capacity, resilient data transport to network nodes located within close physical proximity to all target customers, enabling the HBPW to offer nearly any level of business and residential services.

1

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

The recommended network architecture (Figure 1) places active distribution network switches, Active Ethernet access switches, and Gigabit Passive Optical Network (GPON) Optical Line Terminal (OLT) hardware in hardened shelters and equipment cabinets equipped with backup power and other environmental support systems, aggregating customer connections over multiple, fully redundant 10 Gigabit Ethernet uplinks.

**Figure 1: High-Level FTTP Architecture**

Calix Inc.1035 Network, M, McDowell Blyd.SERIAL NUMBER Petlaumo, CA 94954

TOPENET 8

ENET 4 ENET 8LINE 8TOPENET 7ENET 3ENET 7LINE 8ENET 6ENET 2 S POWERENET 6LINE 8TOPENET LINK 8 ENET LINK 7

ENET 5

TOPENET 1 ENET LINK 6ENET 5LINE 8ENET LINK 510/100/1000 10/100/1000ENET 4LINE 8TOPENET 3LINE 8TOPPOWERTRANSPORTENET 2LINE 8TOPOFF HOOK CPUTOPENET LINK 4ENET 1 LINE 8ENET LINK 3 ENET LINK 2TELEPHONY OUTENET LINK 1RF VIDEO ACC

®C US LISTED RF VIDEOHI PWR IN RFVIDEO5 RFVIDEO6RFVIDEO7RFVIDEO8RFVIDEOHI POWER2

FDC

FDC

FDC

FDC

GPON OLT / Ethernet Switch

GPON 1 GPON 2 GPON 3 GPON 4 SFP 1 SFP 2 SFP 3 SFP 4 SFP 5 SFP 6 SFP 7 SFP 8 XFP 1 XFP 2 SFP + 1 SFP + 2

GPON-4 FAIL SRVCCTRL

GPON 1 GPON 2 GPON 3 GPON 4 SFP 1 SFP 2 SFP 3 SFP 4 SFP 5 SFP 6 SFP 7 SFP 8 XFP 1 XFP 2 SFP + 1 SFP + 2 GPON-4 FAIL SRVCCTRL

**Core Aggregation Switches** *(e.g. Cisco Catalyst 4500-X)* Management /

Service Provisioning Servers Calix E7 -2-

-1-

Primary Hub Sites (Redundant)

Regional networks / upstream ISPs

Local Core Network Systems / backbone fiber

Calix E7

-2-

-1-

CRMJMN

MGT

MGT - 1MGT - 4ACO FTA**Core Routers** *(e.g. Cisco ASR 9006)*

**Internet**

10 GE Backbone Links

Calix E7 -2-

CRMJMN

MGT

-1-

MGT - 1MGT - 4FTAACO

• 2 x 10 GE GPON connections per hub

CRMJMN

MGT

MGT - 1MGT - 4FTAACO

POWERTRANSPORTOFF HOOK

CPUENET LINK 4ENET LINK 3

ENET 2ENET LINK LINK 1RF VIDEO ACC OLT / Ethernet Switch

GPON 1 GPON 2 GPON 3 GPON 4 SFP 1 SFP 2 SFP 3 SFP 4 SFP 5 SFP 6 SFP 7 SFP 8 XFP 1 XFP 2 SFP + 1 SFP + 2

GPON-4 FAIL SRVCCTRL Calix E7 -2-GPON 1 GPON 2 GPON 3 GPON 4 SFP 1 SFP 2 SFP 3 SFP 4 SFP 5 SFP 6 SFP 7 SFP 8 XFP 1 XFP 2 SFP + 1 SFP + 2

GPON-4 SRVCCTRL

FAIL -1-

• Strand capacity to

Space for Open Access support distributed

Equipment

Calix E7 -2- or centralized OLT

-1-

hardware

Calix Network, Inc.1035 Blyd.Petlaumo, M, McDowell CA 94954

SERIAL NUMBER

ENET 8

ENET 4 ENET 8LINE 8TOPENET 7ENET 3ENET 7LINE 8TOPS POWERENET 6ENET 2 ENET 6LINE 8TOPENET LINK 8

ENET LINK 7 ENET 5

ENET 1 ENET LINK 6ENET 5LINE 8TOPENET LINK 510/100/1000 10/100/1000ENET 4LINE 8TOPENET 3LINE 8TOPENET 2LINE 8TOPENET 1 LINE 8TOPTELEPHONY OUTUS LISTED ®C

RF VIDEOHI PWR IN RFVIDEO5 RFVIDEO6RFVIDEO7RFVIDEO8RFVIDEOHI POWERCalix E7

-2--1-

Passive Splitters

Single Fiber Optic Strand to each subscriber tap port

Fiber Distribution Cabinets

The recommended fiber topology provides dedicated “home run” fiber strands from each potential customer to these hub locations, allowing growth in capacity demand to be met by reducing GPON split ratios and/or providing dedicated Active Ethernet connections to certain customers, while supporting any conceivable future access network technology that may

GPON OLT / Ethernet Switch

GPON 1 GPON 2 GPON 3 GPON 4 SFP 1 SFP 2 SFP 3 SFP 4 SFP 5 SFP 6 SFP 7 SFP 8 XFP 1 XFP 2 SFP + 1 SFP + 2 GPON-4 FAIL SRVCCTRL

GPON 1 GPON 2 GPON 3 GPON 4 SFP 1 SFP 2 SFP 3 SFP 4 SFP 5 SFP 6 SFP 7 SFP 8 XFP 1 XFP 2 SFP + 1 SFP + 2

GPON-4 FAIL SRVCCTRL

**GPON OLT / Ethernet Switch**

*(e.g. Calix E7-2)*GPON 1 GPON 2 GPON 3 GPON 4 SFP 1 SFP 2 SFP 3 SFP 4 SFP 5 SFP 6 SFP 7 SFP 8 XFP 1 XFP 2 SFP + 1 SFP + 2

GPON-4 FAIL SRVCCTRL

GPON 1 GPON 2 GPON 3 GPON 4 SFP 1 SFP 2 SFP 3 SFP 4 SFP 5 SFP 6 SFP 7 SFP 8 XFP 1 XFP 2 SFP + 1 SFP + 2

GPON-4 SRVCCTRL

FAIL CRMJMN

MGT

MGT - 1MGT - 4FTAACO

GPON 1 GPON 2 GPON 3 GPON 4 SFP 1 SFP 2 SFP 3 SFP 4 SFP 5 SFP 6 SFP 7 SFP 8 XFP 1 XFP 2 SFP + 1 SFP + 2

GPON-4 FAIL SRVCCTRL

GPON 1 GPON 2 GPON 3 GPON 4 SFP 1 SFP 2 SFP 3 SFP 4 SFP 5 SFP 6 SFP 7 SFP 8 XFP 1 XFP 2 SFP + 1 SFP + 2

GPON-4 FAIL SRVCCTRL

GPON OLT / Ethernet Switch

GPON 1 GPON 2 GPON 3 GPON 4 SFP 1 SFP 2 SFP 3 SFP 4 SFP 5 SFP 6 SFP 7 SFP 8 XFP 1 XFP 2 SFP + 1 SFP + 2

GPON-4 FAIL SRVCCTRL

GPON 1 GPON 2 GPON 3 GPON 4 SFP 1 SFP 2 SFP 3 SFP 4 SFP 5 SFP 6 SFP 7 SFP 8 XFP 1 XFP 2 SFP + 1 SFP + 2

GPON-4 FAIL SRVCCTRL

Approximately 24 Hubs / FDCs

-2-

-1-

-2-

-1-

-2--1-

-2--1-

-2--1-

-2--1-

CRMJMN

MGT - 1MGT - 4MGT FTAACO

CRMJMN

MGT - 1MGT - 4MGT FTAACO

Support for Active Ethernet

AUXDATA (AE) Customers

POWER-48 VDC, 1 ADC(CLASS 2)1 723456

Multiple GPON Networks Per FDC

S POWERRF RETURNRTN ACTIVITY

1:16 and 1:32 splitters for low oversubscription

Optitap-style subscriber taps

FTTP Distribution Plant

Calix Inc.1035 Blyd.Petlaumo, Network, M, McDowell CA 94954

ENET 8

ENET 5

SERIAL NUMBER

ENET 4 ENET 8LINE 8TOPENET 7ENET 3ENET 7LINE 8TOPENET 6ENET 2 S POWERENET 6LINE 8TOPENET LINK 8

ENET LINK 7

ENET 1 ENET 6ENET LINK LINK 5ENET 5LINE 8TOP10/100/1000 10/100/1000ENET 4LINE 8TOPENET 3LINE 8TOPPOWERTRANSPORTOFF HOOK

ENET 2LINE 8TOPSymmetrical, up

CPUENET 4ENET LINK LINK 3

ENET 1 LINE 8TOPENET LINK 2TELEPHONY OUTENET 1RF VIDEO LINK ACC

®C US LISTED AUXRF IN

VIDEO OUT

RF VIDEOHI PWR IN RFVIDEO5 RFVIDEO6RFVIDEO7RFVIDEO8AUXRF

RFVIDEO1RFVIDEO2RFVIDEO3RFVIDEO4RFVIDEOHI POWERto 1 Gbps

AUXDATA

S POWERRF RETURNRTN ACTIVITY

AUXRF IN

VIDEO OUT

AUXRF

RFVIDEO1RFVIDEO2RFVIDEO3RFVIDEO4POWER-48 VDC, 1 ADC(CLASS 2)1 723456

Symmetrical, up

AUXDATA

S POWERRF RETURNRTN ACTIVITY

AUXRF IN

VIDEO OUT

POWER-48 VDC, to 1 Gbps 1 AUXRF

RFVIDEO1RFVIDEO2RFVIDEO3RFVIDEO4ADC(CLASS 2)1 723456

**Approximately 1,000 GPON and AE passings per FDC**

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

emerge. By emphasizing scalability in the longer lasting, underlying physical fiber infrastructure, the HBPW can adopt a more conservative, pay-as-you-grow approach to future network electronics upgrades.

The design model and assumptions employed for cost estimation yield the following totals for certain key metrics:

**Table 1: Summary of Design Model Metrics**

***Physical Plant*** Total passings 28,854 Average Passing density 61 passings per route mile Total hubs 4 Total FDCs 20 Total backbone routes (new and existing) 45.5 miles

Total new backbone routes 2.2 Total distribution plant path 472 Total distribution cable placement 1,091 miles Estimated aerial / underground plant 55% aerial / 45% underground Total new pole attachments 10,604 poles

***Network Electronics*** Total GPON interfaces 928

(14,848 customers at 1:16 split or 29,696 customers at 1:32 split) Total Active Ethernet (1 GE) interfaces 464

Aggregate Access Capacity 2,773 Gbps downstream

1,618 Gbps upstream Aggregate Distribution Network capacity (OLT to Distribution Layer)

3 480 Gbps

Aggregate core capacity (Distribution Layer to Core)

80 Gbps

Maximum oversubscription 1:361

**1.3 Financial Overview** The base case financial analysis we present in this report reflects the revenue needed to cover the cost of serving the HBPW’s entire service area, including the City of Holland and remote areas. The total capital costs (roughly $47.5 million, inclusive of OSP construction and network electronics—not including customer service drops and customer premises equipment), and the ongoing operating costs described in Section 5 are the cost to meet the HBPW’s goal of providing ubiquitous fiber services.

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

In the base case analysis we assume that the HBPW offers three retail services, at prices that compare favorably to similar services in other cities:

• A 1 Gbps residential service at $80 per month,

• A 1 Gbps small commercial service at $85 per month, and

• A 1 Gbps medium commercial service at $220 per month (including service-level agreement)

We also assume that the HBPW will offer two wholesale transport services:

• A 1 Gbps residential service at $62 per month, and

• A 1 Gbps small commercial service at $66 per month

We assume a 39.6 percent take rate for both residential and business customers—and that for each sector, 90 percent will choose 1 Gbps retail service and 10 percent will choose 1 Gbps wholesale transport. (For the business sector, we further assume that 5 percent of businesses will obtain the higher-level retail service, 85 percent will opt for the lower-level retail service.)

The financial analysis for this base case scenario is as follows:

**Table 2: Base Case Financial Analysis with 39.6 Percent Take Rate**

Income Statement 1 5 10 15 20 Total Revenues $ 2,897,082 $ 10,996,344 $ 10,996,344 $ 10,996,344 $ 10,996,344 Total Cash Expenses (2,251,000) (3,790,970) (3,790,970) (3,790,970) (3,790,970) Depreciation (1,893,940) (5,864,230) (3,777,560) (3,716,080) (3,678,700) Interest Expense (1,800,000) (2,427,220) (1,563,910) (766,120) (129,110) Taxes - - - - - Net Income $ (3,047,858) $ (1,086,076) $ 1,863,904 $ 2,723,174 $

3,397,564 Cash Flow Statement 1 5 10 15 20 Unrestricted Cash Balance $ 15,708,492 $ 529,080 $ (232,240) $ 5,951,130 $ 16,035,400 Depreciation Reserve - 2,024,620 2,506,540 1,545,840 3,012,200 Interest Reserve 1,800,000 - - - - Debt Service Reserve 2,250,000 2,250,000 2,250,000 2,250,000 2,250,000 Total Cash Balance $ 19,758,492 $ 4,803,700 $ 4,524,300 $ 9,746,970 $ 21,297,600 The base case scenario also assumes issuance of $62.2 million of debt (combination of loans and bonds). The complete model is provided in Appendix C.

This analysis does not indicate whether obtaining this required take rate is realistic; rather, it reflects the take rate necessary to maintain a positive cash flow, considering all other assumptions in the model. That said, while we did not conduct market research or test the reasonableness of a 39.6 percent take rate, results from other municipalities do suggest that this take rate is possible—although the take rate is dependent on local conditions and the success of the marketing program. For most municipal systems, obtaining a 35 percent take rate is quite

4

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

realistic, while obtaining and maintaining a 40 percent take rate requires an extremely effective marketing program.

We note that most municipal examples are based on a “me-too” triple-play of services that are similar to the incumbent offerings and often compete on price. The proposed HBPW offering is a data-only service that is substantially more robust than other data products available in the area. To date we are aware of two municipal utilities that offer a similar line-up. The first, in Sebewaing, Michigan, is approaching a 60 percent take rate. In Sebewaing’s case, however, the utility faced little competition (DSL and cable modem service in Sebewaing is spotty and unreliable). The second example is Longmont, Colorado. Longmont started offering services a few months ago, and is doing a phased deployment. In neighborhoods where it has deployed, it has seen take rates in the 40 percent range with a $50 per month residential data product.

Given the size of the required capital investment, the HBPW could approach a network deployment in a phased manner. For example, the HBPW could start in the City, and do early deployment where take rates are highest (i.e., building out in neighborhoods where a certain percentage of residents have committed to buying service). Such an approach would lead to ubiquity but, in the short term, would help the HBPW to manage its capital costs and risks.

The phased approach presented in the financial model completes the build in a three-year period—an approach that is quite different to the customer-by-customer way in which the HPBW has grown the existing fiber network. That type of organic growth is not realistic with a residential FTTP build, for a number of reasons. First, FTTP needs to be deployed in clusters of neighborhoods to maintain reasonable fiber construction costs. Second, there would be political pressure if the FTTP build did not deliver ubiquitous coverage in a reasonable deployment period. Extending out the deployment period would likely upset residents who do not have coverage and may create the appearance that the HBPW is red-lining neighborhoods.

**1.4 Recommendations** The HBPW’s planned FTTP enterprise will likely struggle if it attempts to compete with incumbent providers by offering services similar to existing packages (a “me-to” product offering). Instead, it is important to recognize gaps in the existing broadband market and seek to fill those with a unique service offering that incumbents are not currently able to provide. Our analysis suggests that a ubiquitous 1 Gbps service may enable the HBPW to directly serve customers with an exceptional “niche” offering, and avoid competing with “me too” services.

A 1 Gbps service that is expandable to 10 Gbps and beyond may be the differentiator that the HBPW needs to stand out. By focusing on an extremely powerful data-only offering and communicating with users about the potential advantages of a high-performance, unfettered data product, the HBPW may spark the shift in the market it needs to be successful. The goal is

5

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

to focus on *unbundling*, and effectively encouraging consumers to leverage the data service to its fullest capacity—by not emulating traditional providers and focusing on television lineup as a selling feature.1

A 1 Gbps service offering can significantly disrupt the market by enabling over-the-top (OTT) content and enabling consumers to make more flexible choices about the services they subscribe to, and the providers they select. This enables choice and competition in the market.2

The general next steps—which are dependent on the business model pursued—include:

1. Complete required due diligence under the State of Michigan Metro Act 2. Determine whether the HBPW pursues a FTTP business and, if so, determine which model

(retail vs. public-private partnership) 3. Refine business plan and select suppliers/partners

a. Retail model – key suppliers include help desk, peering, bandwidth b. Partnership

i. Conduct RFI/RFP to solicit and assess interest ii. Select partner; define responsibilities, terms, and conditions 4. Begin detailed design

a. Select engineer for detailed design b. Prepare bid documentation

i. Electronics ii. OSP 5. Obtain required authorizations

The cost estimate for initial legal and consulting support is $250,000. The estimate for engineering for the OSP is $6.18 million (see Table 12 for additional details).

1 It may be challenging to attract users who are accustomed to triple play services, but it will be a far greater challenge to compete with incumbent providers by offering the same packages, or “me too” services. 2 Note that this analysis recommends an initial offering of 1 Gbps service. Over time, incumbents may work to challenge the HBPW’s FTTP offering, and the HBPW will have to respond by evaluating its offering and potential changes it should make at that time.

6

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

**2 Assessment of Local Broadband Market** To support our financial analysis of an FTTP expansion of the HBPW’s fiber network, we assessed the current market for residential, small business, and enterprise services within the City of Holland (a primary subset of the HBPW’s service area that can be correlated to Census information and other available market data) . In the sections below, we identify the speeds and pricing for a range of available services; this competitive assessment informs our recommendations for potential HBPW retail offerings (see Section 5).

**2.1 Residential and Small Business Services** Residential and small business customers in the Holland area have access to a range of services, though individual service options are dependent on location. Table 3 lists some of the service providers in the area and the range of advertised download speeds for each type of service that is available in at least some part of HBPW service area.

**Table 3: Overview of Residential and Small Business Data Services in Holland**

**Service Type Provider Advertised Range**

**Download Speed**

**Cable** Comcast 10 Mbps – 2 Gbps

**DSL**

7 AT&T 3 Mbps – 24 Mbps

MegaPath 1.5 Mbps – 6 Mbps

**Satellite** HughesNet 10 Mbps – 15 Mbps

**Internet 3G/4G/Wireless**

**Service Provider** Verizon 5 Mbps – 12 Mbps

**Fixed Wireless** Michwave 2 Mbps – 10 Mbps

**Fiber** HBPW 1 Mbps – 50 Mbps

**2.1.1 Cable** Comcast service is available in much of the City of Holland, as well as some of the surrounding areas, as shown in Figure 2 below.

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

**Figure 2: Comcast Service Area3**

Comcast currently offers Internet service with download speeds from 10 Mbps to 2 Gbps starting at $29.99 per month in some locations in Holland (see Table 4). Promotional rates are available for the first year, after which the rates increase. Discounted prices are available if Internet service is bundled with another service like voice or TV.4

3 National Broadband Map, Comcast Corporation, http://www.broadbandmap.gov/about-provider/comcast- corporation/nationwide/, accessed February 2016. 4 http://www.xfinity.com/locations/internet-service/michigan/holland.html, accessed January 2016.

8

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

**Table 4: Comcast Residential Internet—Internet Only**

**Package Internet Speed Monthly**

**Regular Price**

9 **Monthly Promo Rate**

**Performance Starter** Up to 10 Mbps download $49.95 $19.99

**Performance** Up to 20 Mbps download $66.95 $39.99

**Blast!** Up to 75 Mbps download $91.95 $49.99

**Extreme 150** Up to 150 Mbps download $129.95 $99.99

**XI Gigabit Pro** Up to 2 Gbps download $299.95 -

Comcast advertises its 2 Gbps Gigabit Pro service as available in Holland, but it is only available in locations less than one-third of a mile from Comcast’s existing fiber network, and is subject to a $500 activation fee and a $500 installation fee.5

On the small business side, Comcast offers multiple options with download speeds ranging from 16 Mbps to 150 Mbps (Table 5).6 Bundling with voice reduces the cost by $30 to $40 per month.

5 Todd Ogasawara, “Comcast begins rolling out DOCSIS 3.1-based gigabit home Internet, Extreme Tech, December 29, 2015, http://www.extremetech.com/extreme/220025-comcast-begins-rolling-out-docsis-3-1-based-gigabit- home-internet, accessed February 2016. 6 http://business.comcast.com/internet/business-internet/plans-pricing, accessed January 2016.

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

**Table 5: Comcast Small Business Internet—Internet Only**

**Package Internet Speed (Download/Upload) Monthly Price**

**Starter** Up to 16 Mbps /3 Mbps $69.95

**Deluxe 50** Up to 50 Mbps / 10 Mbps $109.95

**Deluxe 75** Up to 75 Mbps /15 Mbps $149.95

**Deluxe 100** Up to 100 Mbps /20 Mbps $199.95

**Deluxe 150** Up to 150 Mbps /20 Mbps $249.95

**Deluxe 250** Up to 250 Mbps /25 Mbps $349.95

Comcast currently is in the process of upgrading its entire network from Data Over Cable Service Interface Specification (DOCSIS) 3.0 to DOCSIS 3.1. DOCSIS 3.1 uses channel bonding and orthogonal frequency division multiplexing (OFDM) to use available spectrum in the network more efficiently. This upgrade to DOCSIS 3.1 will provide only limited increases in available data capacity initially—approximately 25 percent more compared to DOCSIS 3.0 using the same system capacity—but coupled with more extensive physical upgrades and reconfiguration of the network, will allow the company to reserve a larger portion of the network for data traffic and deliver download speeds of up to 10 Gbps.

Comcast has already transitioned portions of its network in Philadelphia to DOCSIS 3.1, and has announced plans to transition its network in Atlanta, Nashville, Chicago, Detroit and Miami by the end of 2016. The company predicts that its DOCSIS 3.1 enabled gigabit service will be available across “virtually” all of its territory in the next two to three years.7

Unlike Comcast’s fiber-based Gigabit Pro offering, which requires fiber to be installed all the way to the customer premises, the DOCSIS 3.1-based gigabit service can be delivered over the

7 Jon Brodkin, “Comcast 2Gbps fiber available to 18 million homes, gigabit cable coming soon,” *Ars Technica*, February 2, 2016, http://arstechnica.com/business/2016/02/comcast-2gbps-fiber-available-to-18m-homes-gigabit- cable-coming-soon/, accessed February 2016.

10

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

company’s existing hybrid fiber-coaxial (HFC) network, with minimal new construction. Comcast has not yet announced pricing for its gigabit service.8

**2.1.2 DSL** AT&T offers DSL service for residential customers in Holland, starting at as $30 per month for standalone DSL service up to 3 Mbps (download) with a 12-month commitment. Additional options up to 45 Mbps are available as indicated in Table 6.9

**Table 6: AT&T Residential Internet—Internet Only**

**Internet Speed Monthly Regular Price Monthly Promo Rate**

Up to 3 Mbps download $42 $30

Up to 6 Mbps download $52 $35

Up to 18 Mbps download $62 $45

Up to 45 Mbps download $82 $65

AT&T offers DSL-based small business services starting at $60 per month for up to 6 Mbps download/ 1.5 Mbps upload speeds. Additional options up to 24 Mbps are available (Table 7).10

**Table 7: AT&T Business Internet—Internet Only**

**Internet Speed Monthly Price**

Up to 6 Mbps download $60

Up to 12 Mbps download $70

Up to 18 Mbps download $80

Up to 24 Mbps download $90

8 Sean Buckley, “Comcast’s 1Gbps drive could shake up AT&T, Verizon broadband plan,” Fierce Telecom, February 10, 2016, http://www.fiercetelecom.com/story/comcasts-1-gbps-drive-could-shake-att-verizon-broadband- plans/2016-02-10, accessed February 2016. 9 https://www.att.com/shop/u-verse/offers.html, accessed January 2016. 10 https://www.att.com/smallbusiness/content/shop/internet-phone-tv/internet.page, accessed January 2016.

11

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

MegaPath is an Internet service provider (ISP) that offers DSL service to residential customers with a maximum speed of up to 6 Mbps download and 768 Kbps upload. MegaPath also uses a blend of technologies to offer small businesses service in some parts of Holland with a range of speeds11 up to 100 Mbps download and 20 Mbps upload.

Frontier is another ISP that offers 6 Mbps DSL service to residential customers in Holland at an unbundled price of $34.99 per month.12 I2K also offers retail DSL service, which it provides over Frontier and AT&T lines.13

**2.1.3 HBPW Fiber** The HBPW provides point-to-point transport for some residential and business customers. Using this connection, small business customers can receive service ranging from 5 Mbps to 50 Mbps from ISPs that are connected to the HBPW fiber network, including 123Net, Iserv, Sirus, Comlink, and Lynx Network Group. Small business customers must pay a one-time setup fee of $550, engineering and construction fees in some locations, and a monthly rate to both the HBPW and the ISP.14

Currently, Iserv is the only connected ISP offering service to residential customers over the HBPW fiber network; Iserv’s service range from 1 Mbps to 5 Mbps. Residential customers must pay a one-time fee of $200 (or $5 per month for four years), in addition to the Internet connection rates of both HBPW and the ISP. Iserv currently offers residential customers a 1 Mbps symmetrical connection for $30 per month and a 5 Mbps symmetrical connection for $50.15

**2.1.4 Satellite** Satellite Internet access is available across the entire HBPW service area as well.

HughesNet has seven packages available, of which four packages are for Internet services to small businesses. The Select 100 package provides speeds of up to 10 Mbps download and 1 Mbps upload for $79.99 per month, with a 20 GB per month “Business Period” (8 a.m. to 6 p.m.) data allowance and an additional 10 GB anytime allowance, for a total monthly data allowance of 30 GB. The Select 200 and 300 packages provide speeds up to 10 Mbps download and 2 Mbps upload, and offer a higher data allowance during business hours. The Select 400 costs $159.99

11 https://www.megapath.com/services/, accessed January 2016 12 http://internet.frontier.com/plans-pricing.html, accessed January 2016 13 http://www.i2kdsl.com/pricing.htm, accessed January 2016 14 https://www.hollandbpw.com/about-us/broadband/broadband-rates#business-broadband-rates, accessed January 2016 15 Prices based on report of a current Iserv residential customer, reported to HBPW staff member, January 2016.

12

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

per month, offers up to 15 Mbps download and 2 Mbps upload speed, and provides a 50 GB per month data allowance during business hours, and a 10 GB per month anytime allowance for a total monthly data allowance of 60 GB. The three residential packages offer similar speeds and data allowances, and cost between $59.99 and $129.99. All of these packages require a two-year agreement.16

Exede also offers satellite Internet access, with three packages available in the Holland area. All packages provide up to 12 Mbps download and up to 3 Mbps upload, with a 10 GB data allowance costing $59.99 per month, an 18 GB data allowance costing $99.99, and a 30 GB data allowance costing $149.99 per month.17 Parent company ViaSat recently announced plans to launch new satellites that will enable higher tiers of service, up to 100 Mbps. However, the launch is not expected until 2019.18

DISH offers satellite Internet access as well, with prices starting at $49.99 per month for up to 10 Mbps download with a 5 GB data allowance. The top service level costs $79.99 per month for up to 10 Mbps download with a 15 GB data allowance. Both packages are subject to a $10 per month equipment rental fee, and can be packaged with TV and phone service at reduced prices.19

**2.1.5 Wireless** Verizon Wireless offers two 4G LTE data packages with multiple choices for data allowances and pricing, depending on the desired mobility and equipment chosen. LTE-Installed is a data-only 4G LTE service with Wi-Fi connectivity for up to 20 devices and wired Ethernet for up to four devices. Available download speeds are 5 Mbps to 12 Mbps; upload speeds are 2 Mbps to 5 Mbps. Monthly prices range from $60 for a 10 GB data allowance to $120 for a 30 GB data allowance. Overages are charged at $10 per additional GB. A two-year contract is required, with a $350 early termination fee. Verizon offers a $10 monthly deduction for every month completed in the contract.20 Verizon’s Ellipsis JetPack provides a mobile solution, with download speeds of 5 Mbps to 12 Mbps and upload speeds of 2 Mbps to 5 Mbps. Prices for the 12 options of data allowances range from $20 per month for a 2 GB data allowance to $710 per month for 100 GB of data, in addition to a monthly line access charge of $20. The device is $0.99 with a two-year contract. There is a $35 activation fee.21

16 http://business.hughesnet.com/plans-and-pricing/internet-service, accessed January 2016. 17 http://www.exede.com/services-pricing/?zip=49423, accessed January 2016. 18 Mike Freeman, “ViaSat taking satellite broadband global,” *The San Diego Tribune*, February 9, 2016, http://www.sandiegouniontribune.com/news/2016/feb/09/viasat-spacex-eutelsat-boeing-satellite-internet/, accessed February 2016. 19 http://www.dish-systems.com/products/dishnet/, accessed January 2016. 20 https://www.verizonwireless.com/b2c/lte-internet-installed/ accessed January 2016. 21 https://www.verizonwireless.com/b2c/lte-internet-installed/, accessed January 2016.

13

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

Sprint offers 4G LTE wireless data in Holland. The three data packages offered range from a 100 MB per month data allowance for $15 per month, to a 6 GB per month data allowance for $50 per month, to a 12 GB per month data allowance for $80 per month. Each MB over the limit is billed at a cost of $.05. A two-year contract is required, as well as an activation fee of $36 and equipment charges for three different types of devices. There is an early termination fee of $200.

AT&T also provides 4G LTE wireless data service in the area, but only offers one package type with a 5 GB per month download allowance for $50 per month. There is a fee of $10 per 1 GB over the limit. There are also equipment charges, with or without a contract, and an activation fee.

Of the cellular wireless providers in the area, the least expensive wireless data option offered is from T-Mobile, at $20 per month with a limit of 1 GB per month. T-Mobile offers additional capabilities and increasing data limits at incremental costs in a total of six packages, up to $70 per month for up to 11 GB of data. Depending on current promotions, the $35 activation fee is sometimes waived.

Michwave is a Western Michigan-based fixed-wireless ISP with coverage in the eastern and southern outskirts of Holland. Michwave’s packages range from Standard, which provides download speeds of up to 2 Mbps to 3 Mbps for $55 per month, to Super, which provides download speeds of up to 10 Mbps for $90 per month. Installation costs between $150 and $650, depending on the length of the contract.22

**2.2 Enterprise Market** This section provides an overview of competitive providers of dark fiber and lit services for enterprise customers in the City of Holland.

The HBPW’s existing fiber network has already had a major impact on the availability and price of enterprise data transport services in the City. Many of the service providers we identified during the course of our research interconnect with the HBPW fiber network. The HBPW network has improved available service offerings and lowered the cost of new construction necessary for enterprise-grade data transport services.

During the course of our research, we identified 11 service providers in the Holland area that offer a range of enterprise services, from point-to-point connectivity to direct Internet access (DIA), with speeds that range from 1 Mbps to 100 Gbps. Individual providers tailor these services to customers’ requirements (e.g., speed, class of service). Greater proximity to the provider’s existing network infrastructure, or to the HBPW’s existing fiber network, result in lower service

22 http://www.michwave.com/index.php/prices2, accessed January 2016.

14

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

pricing. Providers prefer to offer transport services between locations on their network (“on- net”) and provision Multiprotocol Label Switching (MPLS) based services for connecting locations that are “off-net.”

**2.2.1 Dark Fiber Services** The HBPW leases excess capacity on its existing fiber network for dark fiber services at a rate of $.0105 per foot per strand. We did not identify any other dark fiber available for lease in the Holland area, although Zayo’s fiber network does pass to the east and south of Holland, as seen in Figure 3.

**Figure 3: Zayo Fiber Routes23**

Zayo claims to have proven expertise in deploying major new dark fiber networks and offers multiple financing options, including leases and Indefeasible Right of Use (IRU) agreements. Zayo’s pricing varies significantly depending on whether the building to be connected is On-Net or not; if the location is Off-Net, construction and splicing costs would apply.24 Currently Zayo has no On-Net locations within the HBPW service area.

**2.2.2 Lit Services** Many service providers offer enterprise-grade, Ethernet-based services in Holland. Bandwidths range from 1 Mbps to 100 Gbps. Ethernet service can be classified into three types: Ethernet

23 http://www.zayo.com/solutions/global-network/, accessed January 2016. 24 http://zayofibersolutions.com/why-dark-fiber, accessed January 2016.

15

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

Private Line (EPL or E-Line), Ethernet Virtual Private Line (EVPL), and ELAN. These may be known by different names among different providers.

EPL is a dedicated, point-to-point high-bandwidth Layer 2 private line between two customer locations. EVPL service is similar to EPL but is not dedicated between two locations. Instead, it provides the ability to multiplex multiple services from different customer locations from one point on the provider’s network (multiple virtual connections) to another point on the network. ELAN is a multipoint-to-multipoint connectivity service that enables customers to connect physically distributed locations across a Metropolitan Area Network (MAN) as if they are on the same Local Area Network (LAN).

Internet services over Ethernet are typically classified under two categories: Dedicated Internet Access (DIA) and MPLS IP Virtual Private Networks (IP-VPN). MPLS-based networks can provide dedicated capacity and guaranteed performance levels for real-time applications such as voice and video and are typically priced higher.

The carriers that provide these services in the Holland include the six carriers that interconnect with the HBPW fiber network (123Net, Iserv, Sirus, Comlink, Merit Network, and Lynx Network Group) as well as AT&T, Comcast, EarthLink, MegaPath, Windstream Communications, XO Communications, and Zayo. Prices depend on the bandwidth, location, and network configuration; whether the service is protected or unprotected; and whether the service has a switched or mesh structure.

Iserv offers a range of Internet services using both its own cable network and the HBPW fiber network. Over its cable network, Iserv offers Internet access with download speeds up to 150 Mbps and upload speeds up to 20 Mbps for $355 per month. Using the HBPW fiber network, Iserv offers speeds up to 2 Gbps. The minimum 10 Mbps symmetrical service costs $415 per month, and a 100 Mbps symmetrical service costs $1,950, plus a $550 installation fee and additional construction and engineering fees based on location.25

123Net also uses the HBPW fiber network to provide enterprise services to Holland businesses. It offers symmetrical Internet access at $1,299 per month for 200 Mbps, $1,499 for 500 Mbps, and $2,199 for 1 Gbps. All prices are based on a 60-month contract and are subject to additional construction and engineering fees based on location.26

AT&T has four different types of Ethernet products—GigaMAN, DecaMAN, Opt-E-MAN, and Metro Ethernet. GigaMAN provides a native-rate interconnection of 1 Gbps between customer end points. It is a dedicated point-to-point, fiber optic-based service between customer locations,

25 Prices based on a quote for a new business customer in January 2016. 26 Prices based on a quote for a new business customer in January 2016.

16

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

which includes the supply of the GigE Network Terminating Equipment (NTE) at the customer premises. DecaMAN connects the end points at 10 Gbps and is transmitted in native Ethernet format similar to GigaMAN, only 10 times faster. Opt-E-MAN service provides a switched Ethernet service within a metropolitan area. It supports bandwidths ranging from 1 Mbps to 1,000 Mbps, and configurations such as point-to-point, point-to-multipoint, and multipoint-to- multipoint. Metro Ethernet service provides various transport capabilities ranging from 2 Mbps through 1 Gbps while meeting IEEE 802.3 standards.27

Comcast provides EPL services, which enable customers to connect their customer premises equipment (CPE) using a lower-cost Ethernet interface, as well as using any Virtual Local Area Networks (VLAN) or Ethernet control protocol across the service without coordination with Comcast. EPL service is offered with 10 Mbps, 100 Mbps, 1 Gbps, or 10 Gbps Ethernet User-to- Network Interfaces (UNI) and is available in speed increments from 1 Mbps to 10 Gbps.28

EarthLink offers both MPLS and Ethernet services in Holland. A 100 Mbps Ethernet connection costs $1,550 per month and a 1 Gbps connection costs $6,000 per month. Additional construction fees apply; those vary by location.

MegaPath offers a range of enterprise services in the Holland area with advertised symmetrical speeds up to 1 Gbps. A 1 Gbps Ethernet connection costs $9,898 per month, with a one-time installation fee of $1,334. 29 MegaPath also has lower-cost cable service available with a maximum speed of up to 100 Mbps.30

Windstream Communications has a nationwide presence serving major metropolitan areas— including Holland, where it offers DIA services with speeds up to 1 Gbps.31 However, like Zayo’s network, Windstream’s network only passes the eastern edge of the City, as seen in Figure 4 below. The further a location is from Windstream’s existing network, the higher new construction fees will be.

27 http://www.business.att.com/service\_overview.jsp?repoid=Product&repoitem=w\_ethernet&serv=w\_ethernet&se rv\_port=w\_data&serv\_fam=w\_local\_data&state=California&segment=whole, accessed January 2016. 28 http://business.comcast.com/ethernet/products/ethernet-private-line-technical-specifications, accessed January 2016. 29 Price based on a new business quote obtained January 2016. 30 https://www.megapath.com/services/, accessed January 2016. 31 http://www.windstreambusiness.com/shop/products/mi/holland, accessed January 2016

17

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

**Figure 4 Windstream Fiber Network32**

XO Communications offers carrier Ethernet and DIA services at multiple bandwidth options, from 3 Mbps to 100 Gbps, over its Tier 1 IP network. 33 Although XO Communication prohibits publishing its pricing data, we have shared relevant pricing data with HBPW staff.

32 http://www.windstreambusiness.com/network-data-centers-map, accessed February 2016. 33 http://www.xo.com/carrier/transport/ethernet/, accessed January 2016.

18

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

**3 FTTP Objectives** As part of our analysis of business models the HBPW might want to pursue, we evaluated the HBPW’s goal of ubiquitous service, as well as certain other common broadband objectives that many communities prioritize, and how these may affect the HBPW’s decision-making process. Choosing which goals to prioritize can be challenging; we sought to provide the HBPW with information to empower decisions about its connectivity needs that will have ongoing positive outcomes.

**3.1 Common Community Broadband Objectives** Competition and consumer choice are only two of several objectives that may drive a community’s pursuit of a publicly owned fiber optic network. Many public entities share certain objectives when it comes to considering investment in a community broadband network. Examples of these common goals are as follows:

• Affordability

• Cash flow

• Competition in the market

• Consumer choice

• Ownership and control of assets

• Performance

• Risk aversion

• Ubiquity

Each of these is understandable in the context of what is best for a community, though they do not necessarily all align with one another. In fact, some common objectives that communities prioritize when planning their networks actually conflict with one another. In light of this, communities benefit from careful consideration of which objectives they deem most important to adequately meet their needs.

As an example, risk aversion is top priority for some communities—it may be politically challenging to build a network, and the only way to complete it is to assure key stakeholders and the public that there is minimal risk involved. As we explain below, however, risk aversion is in direct conflict with the goal of building the network throughout an entire community—and that ubiquity may be the most important objective for another community.

Each community must balance its needs so that it can achieve its goals without sacrificing important objectives. Our analysis does not advise the HBPW on which objective(s) it should prioritize; rather, we describe common objectives and explain their roles in communities, how they interact with each other, and some of the potential advantages and disadvantages of each.

19

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

We illustrate in Table 8 below the intersection of common objectives. As the key at the top of the table shows, objectives may have no impact, they may be in alignment, they might conflict, or they may be inapplicable.

**Table 8: Common Goal Alignment**

**A:** Align **C:** Conflict **NI:** No Impact **NA:** Not Applicable

**Ubiquity Choice Competition Ownership Performance Affordability Aversion**

**Risk**

**Cash Flow**

**Ubiquity** *NA* **A A A NI C C C**

**Choice A** *NA* **A A A A C NI**

**Competition A A** *NA* **A A A C NI**

**Ownership A A A** *NA* **A A A C**

**Performance NI A A A** *NA* **NI A A**

**Affordability C A A A NI** *NA* **C C**

**Risk Aversion C C C A A C** *NA* **A**

**Cash Flow C NI NI C A C A** *NA*

In the sections below, we further explain this table and how the objectives listed here interact with one another (i.e., how prioritizing one objective may impact another). Figure 5 below shows a visualization of Table 8 to illustrate the relationship between objectives.

20

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

**Figure 5: Interactions between Objectives**

There are numerous possible outcomes associated with different objectives, and the HBPW has to determine what it believes will best serve its unique needs and have the greatest impact on its community. This analysis does not seek to urge the HBPW in any particular direction, but we do make recommendations about some of the objectives that may well serve any public network.

For example, performance is an objective that either interacts favorably or not at all with other objectives, and prioritizing performance can have a significant positive impact on the FTTP network’s viability by setting it apart from incumbent providers. Thus, there are no real disadvantages to making performance a top priority for the FTTP network because doing so does not have to be at the exclusion of any other objectives. Further, some objectives can and should be pursued in parallel.

**3.2 Ubiquity** For most communities that opt to build and operate a network, ubiquity—which refers to designing and building the network so that it connects every structure in the community—is a key objective. From Connecticut to Minnesota to Oregon, communities (and community

21

**Cash Flow**

**Risk Aversion**

**Performance**

**Affordability**

**Choice**

**Competition**

**Ownership**

**Ubiquity**

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

organizations) large and small have prioritized ubiquity as a primary goal in their broadband pursuits.34

This is a respectable objective for any community, and it makes sense that leaders want to bring service to the entire community—but immediate, communitywide build-out often entails significant risk and cost. The financial risk alone is significant, and in order to make the model sustainable, the service may have to be priced out of some consumers’ reach.

Overall risk aversion conflicts directly with the notion of a full-scale community build-out, as the HBPW will likely face stringent construction deadlines and much higher capital costs than it would if it were to undergo a phased build-out. The need for outside funding is likely also higher with a ubiquitous network build, which greatly increases the HBPW’s risk.

Because the HBPW will likely need to procure financing from an outside source, and due to the high capital investment necessary for large-scale construction, it is likely that the HBPW will be forced to raise monthly service fees. This would reduce the affordability of the HBPW’s FTTP service and to some degree would defeat the purpose of ubiquitous build-out. If the service reaches the entire community but is priced too high for many residents and businesses to afford, the HBPW would fail to meet its goal of providing access to its citizens—because the service would essentially be inaccessible.

Cash flow is another objective that conflicts with ubiquity. The HBPW likely will not expect to make a profit on the FTTP network, but it is important for the entity to become able to financially sustain itself, including operating costs and any debt service payments. This is often referred to as “cash flow” or “breakeven.” The higher cost of building out to every structure in the HBPW service area means that the point at which the FTTP network is able to cash flow will come much later than if the HBPW slowly built out and began generating subscriber revenue earlier in the build-out process.

Figure 6 shows conflicts, alignments, and potential outcomes associated with prioritizing ubiquity.

34 http://www.cnet.com/news/connecticut-communities-join-together-for-gigabit-broadband/. http://broadband.blandinfoundation.org/\_uls/resources/Vision\_Statement\_FINAL\_0228.pdf. https://www.portlandoregon.gov/revenue/article/394185.

22

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

**Figure 6: Ubiquity Alignments, Conflicts, and Potential Outcomes**

**3.3 Consumer Choice** As we noted, localities often pursue open access as a means to increase consumer choice, and this is an important consideration and a high priority for many communities. Incumbent cable and Internet providers may have little economic incentive to expand to areas of the community where they believe they will not recover significant portions of their cost.

An overarching goal of developing an open access network is to level the provider playing field to reduce monopolistic and oligopolistic practices by incumbents, and to give consumers greater choice in service providers.

Most other objectives that a community decides to pursue will interact favorably with consumer choice. A ubiquitous network that fosters open access, boosts competition, and reaches all parts of the community enhances consumer choice on a number of levels. In addition to gaining access to residential services that may have previously been unavailable, consumers often end up with greater flexibility to access services at various community locations. Ubiquity and competition enable enhanced services at community centers, religious institutions, educational facilities, and other locations that benefit residents.

23

1. Affordability 2. Cash Flow 3. Risk Aversion

(+) Service to underserved areas (+) Greater consumer choice (+) Attractiveness for private investment

1. Choice

2. Competition

3. Ownership

**Conflicts**

(–) Need for municipal bonds/loans

**Potential Outcomes**

**Ubiquity**

**Alignments**

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

Affordability of services is an important component in access that ties directly with competition and consumer choice—being able to pay for services is often a major barrier for consumers. Having affordable access to services with competitive speeds can significantly improve quality of life, make residential areas more desirable, and spur business growth. Access to premium residential services at affordable prices can also incite home-based businesses, support continued education, and enable better access to basic human services like healthcare and education.

Risk aversion could negatively impact consumer choice. If the HBPW decides that it will slowly and organically build out its network and does not take steps to prioritize particularly vulnerable areas, it is possible that only the consumers who have traditionally enjoyed provider choice will be positively affected. The HBPW may find that it can balance risk mitigation with community benefit by deliberately funding service to portions of the community that may be undesirable for a private entity. If the HBPW chooses to seek partnership, this could be negotiated.35

**3.4 Competition in the Market** Fostering competition in the market is generally the second component of an open access pursuit. That is, communities often seek to develop an open access infrastructure to enable multiple providers to offer service over the network and enhance competition. Like consumer choice, this is generally a major reason communities attempt to pursue a traditional open access infrastructure. Similar to consumer choice, competition in the market can be achieved through open access in the traditional sense as well as through other means.

The key for most objectives is to determine whether they are primary, how they may conflict with others, and how best to pursue whatever a community deems is its most important goal(s). We believe that competition both upholds and is upheld by all other potential primary objectives—it aligns with, does not impact, or is not impacted by other common community objectives.

Choice and competition go hand in hand, and seeking ways to encourage competition will likely only result in greater consumer choice in communities. Similarly, a ubiquitous network build will probably result in greater competition among local providers. This is not only through providers potentially offering services over the HBPW’s network, but also in the form of incumbent providers lowering prices and enhancing services in response to improved services by other providers.36 This also speaks to competition vis-à-vis affordability and network performance: the

35 The Urbana-Champaign Big Broadband (UC2B) public network negotiated a similar partnership with a private entity. 36 http://www.cnet.com/news/googles-fiber-effect-fuel-for-a-broadband-explosion/, accessed April 2015.

24

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

greater the market competition, the greater the likelihood that other providers will seek to improve their services and lower their prices.

Competition in the market and consumer choice can be prioritized simultaneously with other objectives without negative consequences, and localities often find that focusing on the overall well-being of their communities and citizens has numerous advantages.

It is important to note, however, that there may be some risk involved with creating competition in the market. The service provider industry can be inhospitable, particularly to a public provider. A major challenge faced by networks built and operated by public institutions is opposition from existing, private-sector providers, as we previously noted. There are a number of reasons for this, some of which are related to perception while others relate to the market itself. Criticisms will range from allegations of cross-subsidization of expenses, using general or other funds for debt service coverage, to questioning the need or demand for public based connectivity services.

An important risk that the HBPW should keep in mind is the potential for litigation from objectors ranging from incumbent providers to watchdog groups. Lafayette’s LUS was sued by incumbent providers the same year it proposed creation of a separate utility for fiber-to-the-home-and- business,37 and the Tennessee Cable Telecommunications Association filed a lawsuit against EPB.38 These are only two examples of the litigation that public sector entrants to the market have faced from incumbent providers and others.

**3.5 Ownership and Control of Assets** Retaining ownership of outside plant (OSP) assets is important to mitigate risk; owning assets is an important way for communities to retain some control of the network. This includes a scenario wherein a community pursues partnership with a private provider—a good way to balance risk and reward is for the HBPW to maintain ownership and control of the assets while it assigns operational responsibilities to a private partner. This enables both parties to perform functions that highlight their strengths while not having to expend resources and energy attempting to carry out tasks for which they are ill-equipped.

Cash flow could potentially conflict with ownership and control of assets, depending on to what degree the HBPW chooses to exert control. Maintaining a fiber optic network can be costly, particularly if the HBPW opts to be the retail provider for the service. Operational expenses are a sizable and often unpredictable portion of overall network cost, and it can be difficult to get the take rate necessary to reach cash flow.

37 http://lusfiber.com/index.php/about-lus-fiber/historical-timeline. 38 http://www.chattanoogan.com/2007/9/21/113785/Cable-Group-Files-Suit-To-Try-To-Block.aspx.

25

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

Other objectives either interact favorably or not at all with ownership and control of the assets. If the HBPW retains complete control of the assets, it can make determinations about which provider(s), if any, can offer services over the network. It can regulate which service providers offer services and to what degree, thus allowing for considerable quality control. For example, if a locality offers dark fiber agreements to multiple ISPs, it can determine specific metrics that guide the providers’ service.

Similarly, the HBPW may choose to oversee and maintain the network—a function with which it is already well accustomed and for which it is already staffed to some degree —and rely on a private partner to deliver retail services. The HBPW may also be able to govern price points to support consumer affordability and service speeds to enhance performance. And because the HBPW owns the network itself, it is in control of performance at that level.

**3.6 Performance** Network performance can be a powerful differentiator for a community broadband endeavor. Many communities are already served to some degree by incumbent providers—whether by large national cable or telephone companies or small local ISPs.

Prioritizing performance in a municipal retail offering is not only advantageous, we believe it is necessary to make the offering stand out among existing broadband providers. Market entry is generally a major challenge for municipal retail providers, and even a public–private partnership will likely benefit from focusing on one or two highly specialized offerings to allow it to thrive among incumbents.

The HBPW’s FTTP enterprise will likely struggle and has a greater potential for failure if it attempts to compete with incumbent providers by offering services similar to existing packages. Instead, it is important to recognize gaps in the existing broadband market and seek to fill those with a unique service offering that incumbents are not currently able to provide. Our analysis suggests that a 1 Gbps niche service may enable the HBPW to directly serve customers with an exceptional offering, or will enable a private partnership to enter the market and avoid competing with “me too” services.

A 1 Gbps service that is expandable to 10 Gbps and beyond may be the differentiator that the HBPW needs to stand out. By focusing on an extremely powerful data-only offering and communicating with users about the potential advantages of a high-performance, unfettered data product, the HBPW may spark the shift in the market it needs to be successful. The goal is to focus on *unbundling*, and effectively encouraging consumers to leverage the data service to

26

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

its fullest capacity—by not emulating traditional providers and focusing on television lineup as a selling feature.39

Performance interacts favorably or not at all with other objectives, which is shown in the visual breakdown in Figure 6. There are no disadvantages to prioritizing performance as a key objective in a community build, and we believe that this should be a main focus of any fiber enterprise.

As we noted, a 1 Gbps service offering can significantly disrupt the market by enabling OTT content and enabling consumers to make more flexible choices about the services they subscribe to, and the providers they select. This enables choice and competition in the market.40

As we noted, if the HBPW retains ownership of its assets, it also has better control over performance. The HBPW—whether acting as the retail provider or overseeing a private entity who is serving end user customers—can command the performance that it deems appropriate to best serve the community’s needs.

Risk aversion and cash flow both interact well with performance. We believe that the HBPW minimizes its risk by entering the market with a premium 1 Gbps high performance network. The HBPW can set itself apart from other providers by offering a high-speed data product that incumbents cannot. 41 Further, it can differentiate itself by having an always-on, extremely reliable service that customers can use in new and beneficial ways—like to operate a home-based business, or telecommute to their job, or pursue an advanced degree.

**3.7 Affordability** Affordability is important even in communities that are fortunate to have few low-income areas. While this objective is certainly more important for vulnerable portions of the community, still affordability is often a necessary objective for localities. For example, the HBPW may prioritize affordability in an effort to ensure that its entrepreneurs and tech startups can afford the robust connectivity necessary to support their business endeavors.

There are areas in Holland where demand is likely low enough that private providers are unlikely to build there. Private providers typically cherry pick based on where they determine they are

39 It may be challenging to attract users who are accustomed to triple play services, but it will be a far greater challenge to compete with incumbent providers by offering the same packages, or “me too” services. 40 Note that this analysis recommends an initial offering of 1 Gbps service. Over time, incumbents may work to challenge the HBPW’s FTTP offering, and the HBPW will have to respond by evaluating its offering and potential changes it should make at that time. 41 It is important to note that products like AT&T’s GigaPower and Comcast’s Gigabit Pro do not set their advertised 1 Gbps and 2 Gbps service as a baseline, which is what we have suggested to the HBPW. Rather, these products offer a 10 Mbps to 100 Mbps baseline with the potential to offer 1 Gbps to 2 Gbps service as occasional exceptions. The HBPW, on the other hand, may be able to provide service up to 10 Gbps and beyond with 1 Gbps as its baseline.

27

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

most likely to recover their cost to build. While the HBPW is fortunate that it may not be faced with the choice to potentially offset service costs for a large number of low-income residents, still it may benefit from choosing to invest in infrastructure throughout the community.

Providing affordable service to the entire community would likely create benefit for the City in forms like enhanced quality of life and economic benefit. Further, the HBPW could work with local government agencies to fully leverage benefits that are not monetarily quantifiable. These “benefits beyond the balance sheet” cannot be measured on a financial statement, but their impact communitywide is often profound. Bringing ultra-high speed affordable access to portions of the community that may have previously had little to no access to any connectivity may significantly enhance the quality of life, thus often raising a community’s overall desirability.

As we previously noted, prioritizing ubiquity may come at the exclusion of affordability for some consumers unless the HBPW is able to offset costs in some other way. It could negotiate an agreement with one or more private partners that includes sensitivity to the need for affordable, accessible services in all parts of the community. Similarly, the HBPW may decide that it is politically palatable to subsidize services for certain portions of the community.

Choice, competition, and ownership all interact favorably with affordability. If the HBPW is able to reduce pricing to a level that is attainable to all of its residents, the expansion of choice and the likelihood of increased competition will be notable. And if the HBPW retains ownership of its assets, it can make choices about affordability similar to the control it can exert over performance.

If the HBPW decides to subsidize services, it may find that it becomes more difficult to prioritize risk aversion and cash flow. The more debt and responsibility the HBPW takes on, the higher its risk and the longer it will take for the FTTP network to be cash-flow positive. Similarly, even if the HBPW does not directly subsidize services, prioritizing affordability may mean pricing the product low enough that it is challenging to also prioritize risk aversion and cash flow. It will be important for the HBPW to determine its priorities, and to strike a balance so that one objective is not achieved entirely at the exclusion of another.

**3.8 Risk Aversion** Risk aversion is important, and it is equally important to balance risk and reward. It may take considerably longer to design, build, and deploy a network if risk aversion is the HBPW’s top objective. The “slow and steady” approach is not without merits, but it also does not necessarily give a community a competitive edge. Decreased speed to market—or building out slowly—gives competitors too much time to respond to the HBPW’s approach.

28

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

Figure 7 shows a risk and reward matrix that highlights the HBPW’s most likely low-risk-low- reward, low-risk-high-reward, high-risk-high-reward, and high-risk-low-reward outcomes. The lowest risk with the highest potential reward lies in building the network in a phased approach, specifically based on the Google build-to-demand model.42 This approach signs up a community by neighborhood (known as “fiberhoods” in the Google Fiber model) and once a neighborhood has reached a certain threshold, fiber will be built there.

**Figure 7: Risk and Reward Matrix**

**Risk**

**High Low**

Deploy a ubiquitous communitywide FTTP build, partner with a private provider to operate the retail component, City **d**

maintains ownership and **ra**control of assets

**weR**29 Prioritize risk aversion to avoid bonding, slowly expand network in a

**High**

phased approach and engage private partnership for operation and retail services

**Low**

City attempts to compete with tiered services similar to incumbents – a “me-too” offering.

Maintain current network and do not pursue expansion of services

If the HBPW chooses this approach, it must recognize that it necessarily sacrifices certain other objectives like affordability and consumer choice. Risk aversion will generally come at the expense of objectives like these, and is especially in conflict with a ubiquitous build-out.

These objectives do not have to be mutually exclusive; instead, the HBPW has to decide to what degree it wants to prioritize which objective, and be prepared for possible conflicts and how to mitigate those. For example, if the HBPW chooses a phased approach, it may opt to first expand service to a location that can demonstrate the power of the network. This will support marketing,

42 http://www.wsj.com/articles/google-fuels-internet-access-plus-debate-1408731700

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

and can potentially help convince consumers to sign up for service, thereby achieving ubiquity in a lower risk fashion.

Risk aversion conflicts with ubiquity, choice, competition, and affordability. As we previously noted, it will be challenging to obtain a ubiquitous build-out at all, and especially not within a few years if the HBPW prioritizes risk aversion as its key objective. Because the network is unlikely to be built out quickly in this case, it also reduces the likelihood of increased competition and choice. As we previously noted, the HBPW’s speed to market is critical to secure its potential competitive edge and take full advantage of its unique niche service offering. Further, affordability becomes more difficult to achieve because the HBPW must align service fees to support self-sustaining operations. This means the monthly service will be priced higher to avoid City subsidy.

If the community chooses to prioritize risk aversion, it will align with ownership, cash flow, and performance. Ownership of the assets usually means lower risk for the HBPW because it has greater control and flexibility.

**3.9 Cash Flow** Becoming cash flow positive is a common important goal for any business or entity, and it is also a bit complex to define. Net income is often referred to as “cash flow,” though this is technically incorrect because depreciation is a non-cash expense.

Earnings before interest, taxes, depreciation, and amortization (EBITDA) is the difference between operating revenues and operating expenses; it is a key metric in designing a viable financial model, along with net income. In a capital-intensive business such as an FTTP enterprise, EBIDTA must quickly become positive to keep the enterprise afloat. Net income then deducts interest, taxes, and depreciation. It is also important to note that when EBITDA becomes positive, the business is not necessarily cash flow positive. This is because EBITDA does not include interest on debt, service payments, or capital replenishments. The complete financial analysis needs to include both an income statement (EBITDA and net income) and a cash flow statement.

Revenues are tied to an enterprise’s ability to be sustainable or cash flow positive. Collecting revenues to pay off debt and support business operations bolsters the net income and increases the likelihood that it will become positive.

Several objectives may conflict with cash flow, like affordability, ownership, and ubiquity. As we noted, revenue collection directly impacts cash flow so higher revenues mean a greater likelihood of being cash flow positive. If the service is priced affordably, this may mean lower monthly service fees and a longer path to the enterprise becoming cash flow positive, or self-sustaining.

Ownership may also impact cash flow, especially if the HBPW elects to retain ownership of all network electronics, including customer premises equipment (CPE). Depreciation costs are

30

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

significant, and it is important to reserve funds for equipment and infrastructure replacement. Typically, last mile access network hardware and CPE are replaced after approximately five years, core network equipment is replaced after seven years, and outside fiber and facilities are replaced after 20 to 30 years. Because the useful life of fiber is considered to be 20 years or more, our financial analyses do not account for its replacement.

Another element of ownership in the context of cash flow is the need for network maintenance and locating costs. Because the HBPW already owns a fiber network and has experience with locating, these additional costs will likely be incremental and less significant than a startup enterprise. Yet increased costs associated with serving an increased volume of end users may be significant in terms of both locating and replacing equipment at customer homes and businesses.

31

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

**4 FTTP Network Requirements** The HBPW recognizes the importance of deploying a robust, scalable FTTP infrastructure that can support a wide range of applications and services.

This section describes many of the applications and services that the HBPW’s FTTP expansion will need to support, as well as the general requirements of the FTTP network design. We present the proposed design in Section 5.

**4.1 User Applications and Services** The HBPW’s FTTP network must be able to support “triple play” services—high-quality data, video, and voice—that residential customers have grown accustomed to having in their homes, although this does not mean that the HBPW will be the entity that *directly* provides telephone or cable television services. As Internet technology has improved and network speeds have increased, voice and video services have become available as applications delivered by hundreds of providers over an Internet Protocol (IP) data network connection.

The HBPW can enable residential and small business customers to purchase voice, video, and other over-the-top (OTT)43 services by providing them with unfettered,44 reliable, high-speed Internet access with connections at a minimum of 1 Gbps.45 In other words, the HBPW would become an IP data network provider, either directly or through partnership(s), and would enable its citizens to purchase services—without the HBPW taking a gatekeeper role.

Additionally, the HBPW would continue its “open access” operations, making the network available on a wholesale basis to any qualified provider to offer a data service bundled with Voice- over-Internet Protocol (VoIP),46 cloud storage, or other services. The fiber connection will also support customer-selected applications such as telemedicine, VoIP, the Internet of Things (IoT), video streaming, home security monitoring, and cloud services.

**4.1.1 Internet Access** Internet access is the fundamental service that most residents and small business owners will expect from a fiber connection, and is the prerequisite service for all of the applications described

43 “Over-the-top” (OTT) content is delivered over the Internet by a third-party application or service. The ISP does not provide the content (typically video and voice) but provides the Internet connection over which the content is delivered. 44 Meaning that access to websites offering OTT services is not blocked, restricted, or rate-limited. 45 Rate is a best-effort basis, not a guaranteed speed. Further, it is important to note that with the proposed architecture the HBPW would provide a 1 Gbps baseline service and 10 Gbps and beyond on a case-by-case basis. The baseline can be increased to 10 Gbps and beyond by upgrading the network electronics 46 Telephony (voice) service delivered over an IP data network

32

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

below. The HBPW’s FTTP network will also include one or more peering connections with upstream ISPs, reducing wholesale Internet costs and improving service delivery.

As described in detail below, the FTTP network will support a baseline service level (e.g., 1 Gbps) suitable for residential and small business customers. It will also be capable of supporting higher residential speeds—10 Gbps and beyond—and a range of business and enterprise services.47

**4.1.2 IP Telephony (VoIP) and Video Conferencing** As noted above, VoIP is a voice telephony service delivered over an IP data network.48 In the context of an FTTP access network, VoIP generally refers to an IP-based alternative to Plain Old Telephone Service (POTS) over dedicated copper wiring from a Local Exchange Carrier (LEC). With VoIP, both the live audio (voice) and the call control (signaling) portions of the call are provided through the IP network. Numerous third parties offer this type of full-service VoIP, which includes a transparent gateway to and from the Public Switched Telephone Network (PSTN).

Because VoIP runs over a shared IP network instead of a dedicated pair of copper wires from the LEC, extra design and engineering are necessary to ensure consistent performance. This is how the VoIP services delivered by Comcast (which provides Quality of Service, or QoS, on its network underneath the VoIP services) typically have the same sound and feel as traditional wireline voice calls. In contrast, VoIP services without QoS (such as Skype) will have varied performance, depending on the consistency of the Internet connection. For voice and other real-time services such as video conferencing, network QoS essentially guarantees the perceivable quality of the audio or video transmission.

From a networking perspective, IP-based video conferencing services are fundamentally similar to VoIP. While IP video conferencing is currently less common as a residential application, small and medium-sized businesses in the FTTP domain can be assured that QoS for IP-video conferencing can also be supported, as with VoIP.

**4.1.3 Streaming Video** The variety of online video available through service providers like YouTube, Netflix, Hulu, HBO Go, and others continues to attract users and challenge cable providers’ traditional business models. These are all examples of OTT49 video available over the Internet to users at home or on mobile devices like a smartphone or tablet.

47 Network can support faster connection speeds and other guaranteed service levels to some portion of end users. 48 In this context, voice services are delivered over a data connection. 49 OTT refers to voice, video, and other services provided by a third-party over the Internet rather than through a service provider’s own dedicated network. OTT is also known as “value added” service.

33

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

Traditional cable television providers (also known as linear multi-channel video services) can also deliver content over a fiber connection rather than through a separate coaxial cable connection to users’ homes.

All of these video services can be supported by the HBPW’s FTTP network—as will be locally produced content from the Media Center and public service videos or documentaries filmed by high school students, which can be streamed to residents directly from a school, library, or government building that is on the network. The avenues through which consumers can access content are broadening while the process becomes simpler.

Because of the migration of video to IP format, we do not see a need for the FTTP network to support the Radio Frequency (RF) based video cable television service, an earlier technology used by some providers to carry analog and digital television in native form on a fiber system.

Early municipal providers like Lafayette Utilities System (LUS) and Chattanooga’s Electric Power Board (EPB) found that a data product alone was not strong enough to obtain the necessary market share to make the endeavor viable. Even when Google Fiber entered the Kansas City market in 2011, it found that if it wanted to get people to switch providers, it *had* to offer cable, deviating from its original plan and introducing more cost and complexity than the simple data service it had anticipated. If an OTT cable offering were available when early municipal providers began offering service and when Google entered the Kansas City market, it may have found that offering traditional cable television was unnecessary. More recent municipal FTTP efforts, like Longmont, Colorado, are successfully gaining market share without providing video services. A case study of Longmont is provided in Appendix A.

**4.1.4 Cloud Access** “Cloud services” refers to information technology services, such as software, virtualized computing environments, and storage, available “in the cloud” over a user’s Internet connection. Enterprise and residential customers alike increasingly use cloud services. With the continually rising popularity of mobile devices like smartphones and tablets, consumers want access to their photos, videos, and music from anywhere. And businesses want employees to have access to important information to keep operations running smoothly, even when they are away from the office.

The business drivers behind cloud computing are ease of use and, in theory, lower operating costs. For example, if you are a business owner, the “cloud” theoretically allows you to use large- scale information services and technologies—without needing to have hardware or staff of your own to support it.

34

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

Cloud services eliminate the need to maintain local server infrastructure and software, and instead allow the user to log into a subscription-based cloud service through a Web browser or software client. The cloud is essentially a shift of workload from local computers in the network to servers managed by a provider (and that essentially make up the cloud). This, in turn, decreases the end user’s administrative burden for IT services.

Typically, cable modem and DSL services are not symmetrical—thus incumbent network transfer rates to upload to the cloud are significantly slower than download rates. This can cause significant delays uploading to cloud services.

There are also numerous other cloud services that customers frequently use for non-business purposes. These include photo storage services like Flickr and Shutterfly, e-mail services like Gmail and Hotmail, social media sites like Facebook and Twitter, and music storage services like iTunes and Amazon Prime.

By enabling ISPs to reliably serve residents and small businesses with high-speed services, the HBPW’s FTTP network will increase their options to use the cloud. Improving on less robust connections (e.g., cellular broadband or cable modem services), the HBPW’s network will also enable telecommuters and home-based knowledge workers in Holland to access cloud-based development environments, interact with application developers (both local and remote), and access content distribution network (CDN) development and distribution channels.50

**4.1.5 Over-the-Top (OTT) Programming** As we noted, OTT programming typically refers to streaming content delivered via a consumer’s Internet connection on a compatible device. Consumers’ ubiquitous access to broadband networks and their increasing use of multiple Internet-connected devices has led to OTT being considered a disruptive technology for video-based entertainment. The OTT market, which includes providers like Netflix, Hulu, Amazon Instant Video, and iTunes, is expected to grow from about $3 billion in 2011 to $15 billion, by 2016.51

In order to provision content, OTT services obtain the rights to distribute TV and movie content, and then transform it into IP data packets that are transmitted over the Internet to a display platform such as a TV, tablet, or smartphone. Consumers view the content through a Web-based portal (i.e., a browser) or an IP streaming device (e.g., Google Chromecast, Roku, Apple TV, Xbox 360, or Internet-enabled TV/Smart TV).

50 See, for example: “Amazon CloudFront,” http://aws.amazon.com/cloudfront/ 51 “Over-the-Top-Video – “First to Scale Wins,” Arthur D Little, 2012 http://www.adlittle.com/downloads/tx\_adlreports/TIME\_2012\_OTT\_Video\_v2.pdf

35

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

One potential difference in the delivery of OTT video content to consumers compared to other data traffic is OTT video’s high QoS requirement. QoS prioritizes the delivery of video packets over other data where uninterrupted delivery is not as critical, which ultimately translates to a high quality viewing experience for customers. Content buffering and caching for streamed content reduces the need for QoS. Network QoS is designed for and driven by the need to support real-time services such as VoIP and video conferencing.

OTT providers typically have to use the operators’ IP bandwidth to reach many of their end users. At the same time, they are a major threat to cable television programming, often provided by the very same cable operators, due to their low-cost video offerings. As a result, many cable operators have introduced their own OTT video services to reach beyond the constraints of their TV-oriented platforms and to facilitate multi-screen delivery.52

Even Comcast seemed to embrace OTT by launching its “Streampix” in 2012,53 though that service was less than successful and was ultimately removed as a standalone offering. In 2015, Comcast announced another attempt at providing OTT content in the form of its “Stream” package,54 however subscribers must also sign up for Xfinity Internet in order to access “Stream” content.

While the nature of OTT video lends itself nicely to VoD, time-shifted programming, and sleek user interfaces, OTT providers have limited control over the IP transport of content to users, which can cause strains on network bandwidth due to the unpredictable nature of video demand. Cable operators have experimented with rate limiting and bandwidth caps,55 which would reduce subscribers’ ability to access streaming video content. It is also technically possible for cable operators to prioritize their own traffic over OTT video streams, dial down capacity used by OTT on the system, or stop individual OTT streams or downloads.

Some cable operators have attempted to manage OTT on their networks by incorporating the caching of OTT video content from third-party providers (e.g., Netflix) in their data centers in order to improve QoS and reduce congestion on the cable provider’s backbone network. This serves as a means for improving the quality of OTT video for video hosted in the data center.

52 “Cable operators embrace over the top,” *FierceCable*, July 2, 2013, http://www.fiercecable.com/special- reports/cable-operators-embrace-over-top-video-studios-thwart-netflix-hulu-options 53 http://www.geekwire.com/2012/comcast-unveils-499-month-streampix-service-aim-netflix-hulu/. 54 http://www.forbes.com/fdc/welcome\_mjx.shtml. 55“Comcast tests new usage based internet tier in Fresno,” *Multichannel News*, August 1, 2013 http://www.multichannel.com/distribution/comcast-test-new-usage-based-internet-tier-fresno/144718

36

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

**4.2 Network Design Considerations** This section provides a high-level overview of certain functional requirements used to prepare the conceptual FTTP design and cost estimate. It also presents the technical details of an FTTP network in terms of performance, reliability, and consumer perceptions based on providers’ marketing.

Google changed the industry discussions and customer perceptions of data access when it introduced its plans to deploy an FTTP network and offer a 1 Gbps data connection for $70 per month in Kansas City.56 Until Google entered the FTTP market, cable operators such as Comcast questioned the need for 1 Gbps speeds and typically indicated that 10 Mbps was sufficient for residential and small business users. (Gigabit speeds were available in a few localities, such as Chattanooga, Tennessee, but Google’s brand name meant that Google Fiber had a bigger impact on national awareness around this type of connection.) Since Google’s entry, Comcast and other providers have slowly increased their data offering speeds—moving to 25 Mbps, 50 Mbps, and finally gigabit fiber services in selected markets.

Comcast already advertises its 2 Gbps Gigabit Pro service in Holland. However, the service is only available in locations that are less than one-third of a mile from its existing fiber infrastructure and requires users to pay at least $1,000 in activation and installation fees. Comcast has also announced plans to upgrade its existing hybrid fiber-coaxial (HFC) network to DOCSIS 3.1 across its entire service area, including the City of Holland, by 2018. Initially it will offer 1 Gbps service, but DOCSIS 3.1 is capable of offering as much as 10 Gbps service. Comcast has not yet released pricing for DOCSIS 3.1-based services.57

It is important to note that Internet access speed represents only one portion of the overall Internet experience, and measuring a network’s overall performance on one metric is incomplete. Further, “advertised speed” for residential services is a best-effort commitment, not a guarantee, and does not necessarily reflect actual performance. For example, the advertised speed does not delineate a minimum speed or a guarantee that any given application, such as Netflix, will work all the time.

**4.2.1 Why Fiber Optics** For several decades, fiber optic networks have consistently outpaced and outperformed other commercially available physical layer technologies, including countless variants of copper cabling and wireless technologies. The range of current topologies and technologies all have a place and

56 https://fiber.google.com/cities/kansascity/plans/. 57 Mike Dano, “Comcast: We’ll cover our entire network with 10 Gbps-capable DOCSIS 3.1 tech as soon as 2018,” FierceCable, August 21, 2015, http://www.fiercecable.com/story/comcast-well-cover-our-entire-footprint-10- gpbs-capable-docsis-31-tech-soon/2015-08-21, accessed February 2016.

37

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

play important roles in modern internetworking.58 The evolution of Passive Optical Network (PON) technology has made FTTP architecture extremely cost-effective for dense (and, more recently, even lower and medium-density) population areas.

The specifications and the performance metrics for FTTP networks continue to improve and outperform competing access technologies. In fact, from the access layer up through all segments of the network (the distribution layer and the core, packet-, and circuit-switched transports, and even into the data center), and for almost all wireless “backhaul” communications, optical networking is the standard wireline technology.

Compared to other topologies, fiber-based optical networks will continue to provide the greatest overall capacity, speed, reliability, and resiliency. Fiber optics are not subject to outside signal interference, can carry signals for longer distances, and do not require amplifiers to boost signals in a metropolitan area broadband network.59

If an ISP were to build new with no constraints based on existing infrastructure, it would likely begin with an FTTP access model for delivery of all current services; compared to other infrastructure, an FTTP investment provides the highest level of risk protection against unforeseen future capacity demands. In cases where a provider does not deploy fiber for a new route, the decision is often due to the provider’s long-term investment in copper OSP infrastructure, which is expensive to replace and may be needed to support legacy technologies.

**4.2.2 Fiber Routes and Network Topology** FTTP architecture must be able to support a phased approach to service deployment. Phased deployments can help support strategic or tactical business decisions of where to deploy first, second, or even last. Phasing also allows for well-coordinated marketing campaigns to specific geographic areas or market segments, which is often a significant factor in driving initial acceptance rates and deeper penetration. This is the “fiberhood” approach used by Google and others.

A fiber backbone brings the fiber near each neighborhood, and fiber can be extended as service areas are added in later phases of deployment. This allows for the fiber in individual neighborhoods to be lit incrementally,60 with each new neighborhood generating incremental revenue.

58 An internetwork is a network of interconnected networks. 59 Maximum distances depend on specific electronics—10 to 40 km is typical for fiber optic access networks. 60 As the name implies, “lit fiber” is no longer dark—it is in use on a network, transmitting data.

38

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

The proposed GPON FTTP architecture supports this capability once the core network electronics are deployed and network interconnections are made. The GPON architecture is discussed further in the design report and in Section 4.2.3 below.

In addition to these core considerations, we note that designing the network to support mobile backhaul may allow the HBPW to generate additional revenue from mobile carriers, as well as improve mobile broadband service in the Holland area. Given that this is a longer-term consideration, our financial model does not currently include revenue earned from leasing excess network capacity to cellular providers for mobile backhaul use. We provide more detail on mobile backhaul issues in Appendix B.

**4.2.3 Passive Optical Network—Specifications and Technology Roadmap** The first Passive Optical Network (PON) specification to enjoy major commercial success in the U.S. is Gigabit-capable Passive Optical Network (GPON). This is the standard commonly deployed in today’s commercial FTTP networks and it is inherently asymmetrical. Providers from Google Fiber to Chattanooga’s EPB offer 1 Gbps asymmetrical GPON service with relatively high oversubscription rates (albeit far less than non-FTTP competitors). Our suggested network design allows for provision of symmetrical services ranging from typical levels of oversubscription to dedicated symmetrical capacity per subscriber.

The GPON standard (defined by ITU-T G.984.1) was first established and released in 2004, and while it has since been updated, the functional specification has remained unchanged. There are network speed variants within the specification, but the one embraced by equipment manufacturers and now widely deployed in the U.S. provides asymmetrical network speeds of 1.24 Gbps upstream and 2.49 Gbps downstream.

Since the release of the ITU-T G.984.1 GPON specification, research and testing toward faster PON technologies has continued. The first significant standard after GPON is known by several names: XG-PON, 10GPON, or NG-PON1. The NG-PON1 specification offers a four-fold performance increase over the older GPON standard. Although NG-PON1 has been available since 2009, it was not adopted by equipment manufacturers and has not been deployed in provider networks. We expect the version released in 2015, NG-PON2, to evolve as the de facto next-generation PON standard.

These new standards can be implemented through hardware or software (electronics) upgrades, and are “backward compatible” with the current generation, so all variants can continue to operate on the same network.

The optical layer of the NG-PON2 standard is quite different from GPON. The specification uses a hybrid system of new optical techniques, time division multiplexing (TDM) / wave division

39

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

multiplexing (WDM) PON (TWDM-PON), that basically multiplexes four 10 Gbps PONs onto one fiber, to provide 40 Gbps downstream. This is a 16-fold performance increase over the current GPON standard.

While efforts continue on an ongoing basis by the standards-development community and hardware manufacturers to deliver a WDM-based solution leveraging wavelength-tunable optics to significantly surpass the 10 Gbps barrier, the more recently announced XGS-PON represents an interim solution to facilitate true symmetrical 10 Gbps services (the “S” in “XGS”). The ITU-T announced simultaneously on March 1, 2016 the approval of an amendment to the NG-PON2 standards with the first-stage approval the “XGS-PON” standard.

The XGS-PON physical layer is based on XG-PON specifications (and likely eliminates any potential demand there might have been for XG-PON), operating within the same windows using fixed wavelength optics. Final approval of the standard is expected later in 2016, and some manufacturers expect widespread commercial deployments to begin in 2017—well before NG- PON2 hardware will be widely available or affordable—enabling providers to deliver symmetrical 10 Gbps services over their PON infrastructure while operating in parallel with existing GPON services.

At minimum, the upgrade pathway for existing GPON deployments will require new enhanced small form-factor pluggable (SFP+) modules on the OLT side within the hub building or equipment cabinet, and a new optical network terminal (ONT) device at the customer premises, with software and firmware upgrades on the FTTP electronics. The migration to WDM-based technologies, like NG-PON2, also require the addition of coexistence elements (“CEx”) between the OLT and the PON splitters, which can consist of a range of configurations of passive wavelength filters and couplers. Final details are yet to be announced and will vary by manufacturer, but the NG-PON2 specification requires a migration path and backward compatibility with GPON, facilitated by a coordinated wavelength plan that allows each of these standards to operate over common fiber strands without interfering. FTTP equipment manufacturers are actively testing upgrade steps and strategies for migrating from GPON to NG- PON2.

**Table 9: PON Standards**

**Year Standard** 1994 pi-PON. 50 Mb/s, 1310nm bidirectional, circuit switched 1999 A/B-PON. 622/155 Mb/s, 1550nm down, 1310nm up, ATM-based 2004 G-PON. 2.4/1/2Gb/s, 1490nm down, 1310nm up, packet-based G-PON (2.5) 2009 NG-PON1. 10/2.5Gb/s, 1577nm down, 1270nm up, packet-based XG-PON (10) 2015 NG-PON2. 40G+ capacity XLG-PON (40) 2016 XGS-PON. 10/10 Gb/s, 1577nm down, 1270 up

40

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

**4.2.4 Managing Network Demand** Perhaps the most fundamental problem solved by IP packet data networking is how to cost- effectively design, build, and operate a network to manage unpredictable demands and bursts of network traffic.

The earliest transport networks (and many of the major Internet backbone segments today) are circuit switched. This means that each network leg is a fixed circuit, running at a fixed speed all the time. Fixed-circuit networks are less flexible and scalable, and utilize capacity far less efficiently than packet-switched networks; they must be precisely designed and planned in advance, because there are fewer mechanisms to deal with unplanned traffic surges or unexpected growth in demand.

“Dial-up” modems provide an example of circuit-switched technology. Copper POTS lines were in huge demand as residential and business customers purchased fax machines and accessed the Internet over modems. Because the POTS technologies could not support all of these uses at the same time, and were limited to slower speeds, phone companies were only able to serve that demand by installing more copper lines.

The packet-switched DSL, cable modem, fiber, and wireless technologies that replaced POTS addressed the limitations of fixed-circuit technologies because the flow of network traffic is determined on a per packet basis, and the network provides robust mechanisms for dealing with unexpected bursts of traffic. The trade-off for flexibility, resiliency, and ease of use is that network speed will vary, depending mainly on the amount of traffic congestion.

***4.2.4.1 Oversubscription*** An important balancing act in packet networks is between network performance (speed) and network utilization (efficiency). The primary method of achieving this balance is *oversubscription*. Because the vast majority of network users are not actually transmitting data at any given moment, the network can be designed to deliver a certain level of performance based on assumptions around actual use.

Oversubscription is necessary in all packet-switched network environments and is generally beneficial—by enabling the network operator to build only as much capacity as necessary for most scenarios. By way of comparison, the electric industry uses a demand factor to estimate generation requirements. Similarly, a road that has enough capacity to keep most traffic moving at the speed limit most of the time will get congested during peak travel times—but building a road large enough to handle all of the traffic at peak times would be too expensive. Most drivers

41

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

most of the time have enough room to go the speed limit, but when a lot of users want to be on the road at the same time, everyone has to slow down.

The HBPW will need to evaluate and manage its subscription levels to deliver the optimal balance of performance and efficiency. Although the goal of providing symmetrical *dedicated61* 1 Gbps data to all HBPW subscribers is admirable and technically possible, it may not be very practical or affordable. By comparison, Google’s 1 Gbps offering is technically neither symmetrical nor dedicated. And while Comcast’s 2 Gbps offering might be symmetrical, it is not dedicated.

Services may be burstable, meaning that users may experience the advertised data rates at times, but the average speed will vary greatly based on the traffic being generated over the provider’s distribution network. Performance parameters on a burstable service are rarely publicized or realized. Often a network operator cannot change this parameter without changing the network’s physical connections.

When looking at FTTP requirements, it is important to understand that the speeds and performance stated in marketing material for consumer services are not the same as a network’s actual technical specifications. Actual speeds and performance will depend on the activity of other users on the network. Generally, all residential and small business Internet services are delivered on a best-effort basis and have oversubscription both on the network and in the network’s connection to the Internet.

First, let’s look at network oversubscription. Today’s GPON standard supports FTTP network speeds of up to 2.4 Gbps downstream (to the consumers) and 1.2 Gbps upstream (from the consumers) from a given OLT. Each OLT interface is typically connected to passive optical splitters configured to support up to 32 premises.62 That is, up to 32 users will share the 2.4 Gbps downstream and 1.2 Gbps upstream.63 Given that not all users will demand capacity at the same time and that very few applications today actually use 1 Gbps, a provider can reasonably advertise delivery of a symmetrical 1 Gbps service on a best-effort basis and most consumers will have a positive experience. This level of oversubscription at the GPON “access” layer is quite low compared to most modern cable modem networks, which typically share 150 Mbps – 300 Mbps among several hundred users, even while offering service tiers that “burst” to 150 Mbps.

61 As its name implies, service is “dedicated” when the link runs directly from the ISP to the user. 62 Can be deployed in 8 to 1, 16 to 1, and 32 to 1 configurations. Lower ration’s reduce the number of subscribers sharing the capacity, but increases the number of FDC’s and fiber strands. 63 In an HFC network as used by Comcast, the network capacity is shared among 250 to 500 users.

42

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

NG-PON2 (described above) will likely enable support of 40 Gbps downstream. In four or so years, the NG-PON2 platform should become standard, and although it will initially be somewhat more expensive, pricing will likely quickly match levels similar to today’s 2.4 Gbps platform.

Even with today’s 2.4 Gbps GPON platform, the network can be designed to support 10 Gbps, 100 Gbps, or other symmetrical speeds. This can be accomplished with a hybrid approach using active Ethernet (AE) and GPON, or by deploying a full AE network, which would require placing active electronics inside Fiber Distribution Cabinets (FDCs) in the field.

The next level of oversubscription is generally in the distribution network between the OLT and the service provider’s core network. This portion of the network varies drastically between networks of different size, and is specific to the architecture of a particular network. Most OLT hardware provides 10 Gigabit Ethernet (10 GE) interfaces for uplinks to aggregation switches, frequently with multiple 10 GE interfaces supporting dozens of GPON interfaces (each supporting 16 or 32 customers)—perhaps on the order of 500 or 1,000 customers supported over a pair of redundant 10 GE links. While substantially more oversubscription than at the access layer in a GPON network, most OLT hardware is modularly scalable so that oversubscription can be managed by augmenting uplink capacity as demands grow. Moreover, this layer of the network can generally be upgraded less expensively and, indeed over-engineered in the initial deployment without significantly impacting costs in a relative sense, as the number of network devices and interfaces are far fewer than at the access layer.

The next level of oversubscription is with the network’s access to the Internet. Again, since not all users demand capacity at the same time, there is no need to supply dedicated Internet bandwidth to each residential or small business customer. In fact, it would be cost prohibitive to do so: Assuming a DIA cost of $0.50 per Mbps per month, the network operator would pay $500 per month for 1 Gbps of DIA. But an operator with a residential and small business 1 Gbps service could easily use an oversubscription of 500 to 1,000 on DIA today. Then, as users require more bandwidth, the operator simply subscribes to more bandwidth. The preferential approach is to reduce the traffic over the Internet, which is accomplished by peering to other networks, placing servers (such as Netflix) on the HBPW’s FTTP network (referred to as on-net), and caching.64

All of the applications that the HBPW has identified are possible with 1:32 GPON architecture and reasonable oversubscription. If a bottleneck occurs at the Internet access point, the HBPW can simply increase the amount of commodity bandwidth (DIA) it is purchasing or bring servers such as Netflix on-net. Customers looking for greater than 1 Gbps or who require Committed Interface

64 Network server or service that saves Web pages or other Internet content locally.

43

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

Rates (CIR) can be served via a higher priced Ethernet service rather than the GPON-based 1 Gbps service.

***4.2.4.2 Rate Limiting*** In some networks, unexpected bursts of network traffic slow things down to unacceptable speeds for everyone using the network. Thus there needs to be a mechanism in place to manage these events for the greater good of everyone sharing the network.

One technique for controlling this is called rate-limiting. It can be implemented in many different ways, but the net result is that it prevents over-congestion on a network during the busiest usage times.

Most consumer Internet services today provide subscribers with a “soft” rate for their data connections. This may allow for some extra speed and capacity during times when the network is uncongested, but it may also mean that the “soft” rate may not be achievable during times when the network is the most congested. Providers need to have this flexibility to cost effectively manage the networks overall performance and efficiency and they do this with subscription levels and rate limiting.

**4.2.5 Internet Protocol (IP) Based Applications** The FTTP design will be an all-IP platform that provides a scalable and cost-effective network in the long run. This will allow the HBPW to minimize ongoing costs; increase economies of scale with other network, communications, and media industries; and operate a uniform and scalable network. For example, with an IP-based data network, there would not need to be a separate set of video transport equipment in the headend or hubs, nor a set of dedicated video channels. The transport equipment and the spectrum would become uniform and converge to a single IP platform. Thereafter, network upgrades could be carried out solely based on the evolution of high-speed networking architecture, independent of video processing capabilities often inherent in incumbent provider networks.

**4.2.6 Migration from IPv4 to IPv6 Protocol** The Internet is in the process of migrating from the IPv4 to the IPv6 protocol. This upgrade will include several improvements in the operation of the Internet. One of the most notable is the increase in available device addresses, from approximately four billion to 3x1038 addresses. IPv6 also incorporates other enhancements to IP networking, such as better support for mobility, multicasting, security, and greater network efficiency; it is being adopted across all elements of the Internet, such as equipment vendors, ISPs, and websites.

Support of IPv6 is not unique to the proposed HBPW FTTP network. Comcast has begun migrating all of its services to IPv6.

44

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

Customers with access to IPv6 can connect IPv6-aware devices and applications through their data connection and no longer need to use network address translation (NAT) software and hardware to share the single IP address from the ISP among multiple devices and applications. Each device can have its own address, be fully connected, and (if desired) be visible to outside networks.

One way to think of removing NAT is that it is the IP equivalent of moving from a world of cumbersome telephone systems with a main number and switchboard extension (e.g., 616-555- 0000 extension 4422) to one where each individual has a unique direct number (e.g., 616-555- 4422). Devices and applications that will particularly benefit from IPv6 include interactive video, gaming, and home automation, because NAT (and other IPv4 workarounds to share limited address space) makes connecting multiple devices and users more complex to configure, and IPv6 will eliminate that complexity and improve performance. With IPv6, each device and user can potentially be easily found, similar to how a phone is reached by dialing its phone number from anywhere in the world.

**4.2.7 Multicasting—IP Transport of Video Channels** Traditional Internet video can waste capacity, especially in a “channel” video environment, because it sets up a new stream from the source to each viewer. Even if many people are watching the same program at the same time, a separate copy is streamed all the way from the server (or source) to the user. *Multicasting* is a method of transmitting data to multiple destinations by a single transmission operation in an IP network.

Using multicasting, a cable operator (leveraging the proposed FTTP network) can send a program to multiple viewers in a more efficient way. A multicast-aware network sends only a single copy of any given video stream from its source through the various network routers and switches within the network. When a viewer selects the program, the viewer’s device (set-top converter or computer) requests the multicast stream, a copy of which is then provided to that customer by the underlying network—rather than the originating video server or encoder sending a dedicated unicast stream to that customer, as is the case with OTT video services and other Internet-based video applications. Thus, the stream exists only once over any given segment of the network upstream from the access layer, so even if many neighbors are viewing the same stream, multicast video services can never occupy more capacity than the sum of one copy of each video stream (see Figure 8 and Figure 9).

45

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

**Figure 8: Unicast IP Network Carries Multiple Copies of Single Video Channel**

46

**Figure 9: Multicast IP Network Carries Single Copy of Single Video Channel**

Only one copy of any video stream at any given time

Multiple copies of the same video stream

**IP Multicast Video Delivery** - Only one copy of any video stream is required over each network link

IP Unicast Video Delivery - Each customer receives a dedicated video stream from the source

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

Multicast is a feature that was optional in IPv4 but standard (and better executed) in IPv6. As multicast-capable and multicast-aware routers and set-top converters become standard, a cable operator and OTT video providers leveraging the HBPW’s FTTP network could consider an all-IP video programming offering, and not just video-on-demand (VoD), as multicast provides a means to carry traditional channels over IP without wasting the backbone capacity.

**4.3 Target User Groups** Based on our discussions with HBPW staff, we identified two primary categories of potential network users (in addition to the electric utility):

• Residents

• Small businesses and enterprise users

To analyze the user groups, we first estimated the possible number of “passings”—homes and businesses the fiber could potentially pass—for each. Using GIS data, we estimated that there are 28,854 total passings in the HBPW service area. This number is based on the latest electric service drop data provided by the HBPW. Of the 28,854 potential passings, we assume that 24,144 are residential passings while 4,710 are commercial passings.

**4.3.1 Residents** The HBPW’s primary focus—and the largest potential user group for a HBPW FTTP network—is the residential market. We estimated that there are 23,949 residential passings in HBPW’s service area. These do not include households in buildings with 20 or more units.

Residents will require a diverse range of speeds and capabilities—from simple, reliable connectivity at low cost, to extremely high speed, symmetrical services that can support hosting and research and development applications. The fiber network will provide the capability to offer a range of services through the same physical medium, requiring only an upgrade of electronics or software at the user premises, rather than customized physical connections, to deliver higher- capacity services.

**4.3.2 Small Businesses and Enterprise Users** We estimate that there are 4,710 commercial passings across the HBPW’s service area. In terms of their broadband needs, these small businesses are often more similar to high-capacity residential users than to large enterprise customers. They may need more than just a basic connection, but do not typically require the speeds, capacity, or guaranteed service levels that a large organization or high-end data user needs.

The HBPW’s FTTP network must support small businesses and be capable of supporting select institutions and enterprise users. It is important to emphasize that the suggested network design

47

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

will have enough fiber capacity to provide either Active Ethernet service or Passive Optical Network (PON) service to any business or resident. Our design and cost estimates provide for a conservative business analysis with sufficient fiber strands and network electronics capacity to meet near term demands at nearly any take rate, and includes Active Ethernet (dedicated symmetrical gigabit) hardware support for approximately 10 percent of all business passings. With the recommended network in place, HBPW or another ISP will be able to sell customized service to enterprise customers on a case-by-case basis.

The FTTP network will support basic service levels at virtually any level, complementing the HBPW’s dark fiber leasing program by addressing a different market segment. That is, the FTTP offering will serve users whose connectivity needs are not significant enough to warrant executing a dark fiber agreement, but who might require dedicated lit connections of up to 10 Gbps and greater. Similarly, the dark fiber licensing program successfully provides service to users whose connectivity needs would likely not be sufficiently met by an FTTP offering.

48

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

**5 FTTP Backbone Conceptual Design and Cost Estimates** This section offers a conceptual design model and implementation cost estimates to meet the requirements described in the previous sections, and discusses considerations to help guide implementation phasing and detailed design decisions.

**5.1 FTTP Network Design** The physical outside plant (OSP) is both the most expensive part of the network and the longest lasting. The architecture of the physical plant determines the network’s scalability for future uses and how the plant will need to be operated and maintained; the architecture is also the main determinant of the total cost of the initiative. Within this category of expenses, we include supporting infrastructure, including physical shelters for electronics, electrical power systems, and environmental control components.

Higher layer components include the OLT hardware (access layer); distribution network switches; and core network routers and switches; and network management systems—and depending on the business model and role of a given network operator, might also include the application-layer systems required for the delivery of video content, voice and video communications, home automation services, and so on. In this case, we include only those systems pertinent to the delivery of high-speed Internet services, but which can also support any range of voice, video, and other interactive services that one or more service providers might want to deliver as OTT Internet-based service or out-of-band using dedicated fiber and/or lit capacity within the active FTTP network.

The particular technical approach and network electronics architecture drive certain baseline requirements for the underlying fiber optic infrastructure, such as fiber strand capacity requirements in certain segments of the network, type and quantity of outdoor equipment and fiber distribution cabinets, and requirements for physical path diversity of backbone connections. In consideration of the relatively long lifespan of the fiber infrastructure compared to particular network electronics options, service offerings, or even business models, the system-level design developed for purposes of our cost estimates assumes a best-in-class approach that is flexible enough to accommodate a wide range of short-term and long-term technical approaches.

The recommended design is a hierarchical data network with different attributes at each layer, targeting a balance of critical scalability and flexibility, both in terms of the initial network deployment and capability to accommodate the increased demands of future applications and technologies.

The functional objectives driving this hierarchical FTTP data network are:

49

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

• ***Capacity –*** ability to provide efficient transport for subscriber data, even at peak levels, supporting any passive splitting ratio and/or dedicated fiber connections to each customer, with little or no oversubscription except at the core layer where peering occurs with upstream ISPs so that capacity can be increased readily as demands dictate;

• ***Availability and physical path diversity –*** provide high levels of redundancy, reliability, and resiliency to quickly detect faults and re-route traffic around diverse fiber paths in the event of a fiber break or equipment failure, with the option to place active backbone nodes located within close proximity to every potential customer and interconnected over diversely routed backbone rings;

• ***Scalability –*** ability to grow in terms of physical service area and increased data capacity, and to integrate newer technologies, with sufficient fiber capacity to support ongoing reduction of PON split ratios and/or increase in dedicated Active Ethernet connections.

• ***Flexibility –*** ability to provide different levels and classes of service into different customer environments, as well as the ability to support an open access network or a single-provider network. Separation between service providers can be provided on the physical (separate fibers) or logical (separate VLAN or VPN) layers.

• ***Security –*** controlled physical access to all equipment and facilities, plus network access control to devices.

**5.1.1 Design Overview and Key Metrics** The network design model includes a backbone network layer providing connectivity between hub facilities and fiber distribution cabinets (FDC) located throughout the HBPW electric service area. Hub and FDC locations were chosen primarily to coincide with HBPW properties, and in certain cases, placed within the public right-of-way or on City or County properties. To the extent possible, the backbone design aligns with existing HBPW fiber resources, maximizing the potential cost savings associated with the use of this fiber and/or the existing fiber pathways, particularly for crossings of railroad tracks, bodies of water, and highways—all of which are considerations in this case.

Furthermore, we sought to identify candidate hub locations such that the service areas for each could be defined to encompass roughly the same number of serviceable passings. Specifically, the backbone design targets a density of approximately 1,000 passings per hub / FDC, creating service areas for each that can be accommodated through a consistent configuration of network electronics and physical cabinet layout—an important consideration for maintenance and support efficiencies. Figure 10 illustrates this backbone design, including candidate hub locations.

50

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

**Figure 10: FTTP Network Backbone**

The backbone network, consisting of approximately 45 miles of fiber routes, almost all of which are aligned with existing HBPW fiber routes, provides fully diverse connectivity between four primary hub locations and 20 FDCs. Coupled with an appropriate network electronics

51

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

configuration, this design serves to greatly increase the reliability of fiber services provided to the customers compared to that of more traditional cable and telephone networks. The backbone design minimizes the average length of non-diverse distribution plant between the provider’s electronics and each customer (much less than a mile, in most cases), thereby reducing the probability of service outages caused by a fiber break.

For the sake of cost estimation, we assume the backbone network will include:

• Equipment shelters located at four primary hub sites, functioning as core and distribution- layer hubs to support redundant core network electronics. The hub structure will likely consist of a pre-fabricated concrete shelter (approximately 10-foot by 12-foot), equipped with redundant air conditioners, backup generator and uninterruptible power supplies, and inert gas fire suppression system;

• FDCs placed at approximately 20 additional locations along the backbone fiber routes, functioning as active distribution hubs suitable to support hardened network electronics with backup power and an active heat exchanger; and

A dedicated fiber cable of at least 288-strand count.

Figure 11 illustrates the recommended reference design model for the FTTP network. The drawing illustrates the primary functional components in the FTTP network, their relative position to one another, and the flexible nature of the architecture to support multiple subscriber models and classes of service.

52

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

**Figure 11: High-Level FTTP Architecture**

Calix Inc.1035 Blyd.Petlaumo, Network, M, McDowell CA 94954

SERIAL NUMBER

ENET 8ENET 4ENET 8 LINE 8TOPENET 7ENET 3ENET 7 LINE 8TOPS POWERENET 6ENET 2

ENET 6 LINE 8TOPENET LINK 8

ENET LINK 7 ENET 5ENET 1ENET 6ENET LINK LINK 5ENET 5

LINE 8TOP10/100/1000 10/100/1000ENET 4 LINE 8TOPENET 3 LINE 8TOPPOWERTRANSPORTENET 2 LINE 8TOPOFF HOOK

CPUENET LINK 4ENET 1 LINE 8TOPENET LINK 3

ENET 2ENET LINK LINK 1TELEPHONY OUTRF VIDEO ACC

US LISTED ®C

RF VIDEOHI PWR IN RFVIDEO5 RFVIDEO6RFVIDEO7RFVIDEO8RFVIDEOHI POWER53

FDC

FDC

FDC

FDC

GPON OLT / Ethernet Switch

GPON 1 GPON 2 GPON 3 GPON 4 SFP 1 SFP 2 SFP 3 SFP 4 SFP 5 SFP 6 SFP 7 SFP 8 XFP 1 XFP 2 SFP + 1 SFP + 2

GPON-4 FAIL SRVCCTRL

GPON 1 GPON 2 GPON 3 GPON 4 SFP 1 SFP 2 SFP 3 SFP 4 SFP 5 SFP 6 SFP 7 SFP 8 XFP 1 XFP 2 SFP + 1 SFP + 2

GPON-4 SRVCCTRL

FAIL **Core Aggregation Switches** *(e.g. Cisco Catalyst 4500-X)* Management /

Service Provisioning Servers Calix E7 -2--1-

Primary Hub Sites (Redundant)

Regional networks / upstream ISPs

Local Core Network Systems / backbone fiber

Calix E7 -2--1-

CRMJMN

MGT

MGT - 1MGT - 4FTAACO

**Core Routers** *(e.g. Cisco ASR 9006)*

**Internet**

10 GE Backbone Links

Calix E7

-2-CRMJMN

MGT -1-

MGT - 1MGT - 4ACO FTA• 2 x 10 GE

GPON connections per hub

CRMJMN

MGT

MGT - 1MGT - 4FTAACO

POWERTRANSPORTOFF HOOK

CPUENET 4ENET LINK LINK 3

ENET LINK 2ENET 1RF VIDEO LINK ACC OLT / Ethernet Switch

GPON 1 GPON 2 GPON 3 GPON 4 SFP 1 SFP 2 SFP 3 SFP 4 SFP 5 SFP 6 SFP 7 SFP 8 XFP 1 XFP 2 SFP + 1 SFP + 2 GPON-4 Calix E7

FAIL SRVCCTRL

-2-

GPON 1 GPON 2 GPON 3 GPON 4 SFP 1 SFP 2 SFP 3 SFP 4 SFP 5 SFP 6 SFP 7 SFP 8 XFP 1 XFP 2 SFP + 1 SFP + 2

GPON-4 FAIL SRVCCTRL

-1-

• Strand capacity to

Space for Open Access support distributed

Equipment

Calix E7 or centralized OLT

-2--1-

hardware

Calix Inc.1035 Network, M, McDowell Blyd.SERIAL NUMBER Petlaumo, CA 94954

TOPENET 8ENET 4ENET 8 LINE 8TOPENET 7ENET 3ENET 7 LINE 8ENET 6ENET 2 S POWERENET 6 LINE 8TOPENET LINK 8

ENET LINK 7 ENET 5ENET 1ENET 6ENET LINK LINK 5ENET 5

LINE 8TOP10/100/1000 10/100/1000ENET 4 LINE 8TOPENET 3 LINE 8TOPENET 2 LINE 8TOPENET 1 LINE 8TOPTELEPHONY OUT®C US LISTED RF VIDEOHI PWR IN

RFVIDEO8RFVIDEO7RFVIDEO6RFVIDEO5

RFVIDEOHI POWERCalix E7

-2-

-1-

Passive Splitters

Single Fiber Optic Strand to each subscriber tap port

Fiber Distribution Cabinets

The distribution fiber plant, encompassing the physical fiber cable from the hubs to the customers, is based on a “home-run” fiber architecture—meaning a dedicated fiber strand is available from a given hub to each passing. Compared to more traditional FTTP designs that generally employ optical splitters in the field (between the hubs and the premises in the figure above), thereby reducing the size of “feeder” cables, this design requires larger strand-counts and hub facilities capable of terminating a greater quantity of fiber strands.

This home-run architecture offers greater scalability to meet long-term needs, and is consistent with best practices for an open access network model that might potentially be required to support multiple network operators, or at least multiple retail service providers requiring dedicated physical connections to some or all customers. Whether centralizing network

GPON OLT / Ethernet Switch

GPON 1 GPON 2 GPON 3 GPON 4 SFP 1 SFP 2 SFP 3 SFP 4 SFP 5 SFP 6 SFP 7 SFP 8 XFP 1 XFP 2 SFP + 1 SFP + 2

GPON-4 FAIL SRVCCTRL

GPON 1 GPON 2 GPON 3 GPON 4 SFP 1 SFP 2 SFP 3 SFP 4 SFP 5 SFP 6 SFP 7 SFP 8 XFP 1 XFP 2 SFP + 1 SFP + 2

GPON-4 FAIL SRVCCTRL

**GPON OLT / Ethernet Switch**

*(e.g. Calix E7-2)*GPON 1 GPON 2 GPON 3 GPON 4 SFP 1 SFP 2 SFP 3 SFP 4 SFP 5 SFP 6 SFP 7 SFP 8 XFP 1 XFP 2 SFP + 1 SFP + 2

GPON-4 SRVCCTRL

FAIL GPON 1 GPON 2 GPON 3 GPON 4 SFP 1 SFP 2 SFP 3 SFP 4 SFP 5 SFP 6 SFP 7 SFP 8 XFP 1 XFP 2 SFP + 1 SFP + 2

GPON-4 FAIL SRVCCTRL

CRMJMN

MGT

MGT - 1MGT - 4ACO

FTA

GPON 1 GPON 2 GPON 3 GPON 4 SFP 1 SFP 2 SFP 3 SFP 4 SFP 5 SFP 6 SFP 7 SFP 8 XFP 1 XFP 2 SFP + 1 SFP + 2

GPON-4 FAIL SRVCCTRL

GPON 1 GPON 2 GPON 3 GPON 4 SFP 1 SFP 2 SFP 3 SFP 4 SFP 5 SFP 6 SFP 7 SFP 8 XFP 1 XFP 2 SFP + 1 SFP + 2

GPON-4 FAIL SRVCCTRL

GPON OLT / Ethernet Switch

GPON 1 GPON 2 GPON 3 GPON 4 SFP 1 SFP 2 SFP 3 SFP 4 SFP 5 SFP 6 SFP 7 SFP 8 XFP 1 XFP 2 SFP + 1 SFP + 2

GPON-4 FAIL SRVCCTRL

GPON 1 GPON 2 GPON 3 GPON 4 SFP 1 SFP 2 SFP 3 SFP 4 SFP 5 SFP 6 SFP 7 SFP 8 XFP 1 XFP 2 SFP + 1 SFP + 2

GPON-4 FAIL SRVCCTRL

Approximately 24 Hubs / FDCs

-2-

-1-

-2-

-1-

-2--1-

-2--1-

-2--1-

-2--1-

CRMJMN

MGT - 1MGT - 4MGT FTAACO

CRMJMN

MGT - 1MGT - 4MGT FTAACO

Support for Active Ethernet

AUXDATA (AE) Customers

POWER-48 VDC, 1 ADC(CLASS 2)1 723456

Multiple GPON Networks Per FDC

S POWERRF RETURNRTN ACTIVITY

1:16 and 1:32 splitters for low oversubscription

Optitap-style subscriber taps

FTTP Distribution Plant

Calix Network, Inc.1035 Blyd.Petlaumo, M, McDowell CA 94954

SERIAL NUMBER

ENET 8ENET 4ENET 8

ENET 7ENET 3ENET 6ENET 2

ENET 5ENET 1ENET 10/100/1000 10/100/1000ENET 4

LINE 8TOPENET 7

LINE 8TOPSymmetrical, up TOPS POWERENET 6 LINE 8ENET LINK 8 ENET LINK 7

TOPENET LINK 65 LINE 8ENET LINK 5LINE 8TOPTOPENET 3 LINE 8POWERTOPTRANSPORTENET 2 LINE 8OFF HOOK CPUTOPENET LINK 4ENET 1 LINE 8ENET LINK 3 ENET LINK 2TELEPHONY OUTENET LINK 1RF VIDEO ACC

®C US LISTED AUXRF IN

RFVIDEO5

RFVIDEO6VIDEO OUT

RFVIDEO7RFVIDEO8RF VIDEOHI PWR IN

AUXRF

RFVIDEO1RFVIDEO2RFVIDEO3RFVIDEO4RFVIDEOHI POWERto 1 Gbps

AUXDATA

S POWERRF RETURNRTN ACTIVITY AUXRF IN

VIDEO OUT

POWER-48 VDC, 1 RFVIDEO4RFVIDEO3RFVIDEO2RFVIDEO1AUXRF

ADC(CLASS 2)1 723456

Symmetrical, up

AUXDATA

S POWERRF RETURNRTN ACTIVITY

AUXRF IN

VIDEO OUT

AUXRF

RFVIDEO1RFVIDEO2RFVIDEO3RFVIDEO4POWER-48 VDC, to 1 Gbps

1 ADC(CLASS 2)1 723456

**Approximately 1,000 GPON and AE passings per FDC**

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

electronics in the primary hub locations and including only passive splitters in each FDC, deploying a combination of active and passive components, or implementing a fully active Ethernet network with dedicated connections to each customer, this design model fully supports any of these technical approaches.

The design model assumes placement of manufacturer-terminated fiber “taps” within the right- of-way or HBPW easements, providing environmentally hardened fiber connectors for customer service drop cables. This is an industry-standard approach to minimize customer activation times and reduces the potential for damage to distribution cables and splices by eliminating the need for service installers to perform splices in the field. The design model and assumptions employed for cost estimation yield the following totals:

**Table 10: Summary of Design Model Metrics**

***Physical Plant*** Total passings 28,854 Average Passing density 61 passings per route mile Total hubs 4 Total FDCs 20 Total backbone routes (new and existing) 45.5 miles

Total new backbone routes 2.2 Total distribution plant path 472 Total distribution cable placement 1,091 miles Estimated aerial / underground plant 55% aerial / 45% underground Total new pole attachments 10,604 poles

***Network Electronics*** Total GPON interfaces 928

(14,848 customers at 1:16 split or 29,696 customers at 1:32 split) Total Active Ethernet (1 GE) interfaces 464

Aggregate Access Capacity 2,773 Gbps downstream

1,618 Gbps upstream Aggregate Distribution Network capacity (OLT to Distribution Layer)

54 480 Gbps

Aggregate core capacity (Distribution Layer to Core)

80 Gbps

Maximum oversubscription 1:361

**5.1.2 Backbone and Primary Hub Sites** The primary hub sites in an FTTP network generally contain core network electronics that aggregate physical connectivity from the access and distribution layers of the networks, and may

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

also contain servers and other systems related to the provision of particular services and applications. The proposed network design includes four primary hub sites comprised of equipment shelters providing secure datacenter-like environments for sensitive network electronics—one each located at the following sites:

• Hub A – James DeYoung Power Plant, 64 Pine Ave.

• Hub D – Service Center, 625 Hastings Ave.

• Hub G – Ottawa Ave. Substation

• Hub R-–James St. Substation

Each of the primary hub shelters will be capable of hosting Operational Support Systems (OSS) for one or more providers, such as provisioning servers, fault and performance management systems, and remote access systems. Each provides a point-of-presence for any business partner, content provider, or service provider for collocation purposes, and to gain access to the subscriber network to deliver services via the FTTP network. Furthermore, providers and businesses can gain access to these core resources at any location along the diversely routed backbone ring in the event space requirements or physical access needs demand separate facilities for a given provider or customer.

For cost estimation purposes, we assume that primary hubs will involve the placement of a precast concrete shelter providing an operating environment similar to that of a data center. This includes clean power sources, UPS batteries, and diesel power generation for survival through sustained commercial outages. The facility must provide strong physical security, limited/controlled access, environmental controls for humidity and temperature, and an inert gas fire suppression system.

Although these will be located at existing HBPW facilities, constructing these as dedicated shelters allows access to be controlled for outside contractors and staff responsible for FTTP operations—and conversely, to limit the need to provide access for these individuals to electric substations and other HBPW utility infrastructure outside of their purview.

55

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

**Figure 12: Sample Hub Facility**

In the proposed design, Hubs A and D will house core, distribution, and access-layer network components. Hubs G and R will house distribution and access layer network components, and will serve as launching points for expansion of the network beyond the currently anticipated service area.

The distribution network is the layer between the network core and the access electronics that facilitates the final connections to the customers, and can comprise multiple physical and electronic aggregation points that vary in function and scale depending on the specific design. In this model, each of the four primary hubs functions as distribution node, and also contains access network electronics and passive splitter components.

All four primary hubs will be interconnected over diversely routed backbone rings forming high availability core and distribution layers, including aggregation of redundant and diversely routed uplinks from access OLT hardware. Each primary hub site will be equipped with distribution layer switches capable of high-density aggregation of 10 GE connections from the access-layer OLT hardware.

The primary hubs will serve as peering points for outside connections; house core systems for third-party service providers leveraging the HBPW network as a last mile open access provider; and facilitate dedicated connections to high-end business customers requiring connections at speeds of 10 Gbps, or greater.

Attachment 1 illustrates the physical fiber topology of the backbone network; Attachment 2 provides a logical depiction of the network electronics layers and their connectivity; Attachment 3 illustrates the physical backbone fiber routes; and Attachment 5 provides a detailed bill of

56

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

materials (BOM) for candidate network electronics, including core and distribution network electronics. We note that our pricing is based on Cisco hardware at anticipated discount levels to offer a conservative estimate for a scalable architecture, though a wide range of manufacturers, including Juniper, Ciena, Alcatel-Lucent, Avaya, Brocade, and others have competitive offerings in some or all of the required categories.

**5.1.3 Access Network Hubs and Electronics** Access network electronics will be housed primarily in Fiber Distribution Cabinets (FDCs) located throughout the service footprint. FDCs can be placed in the right-of-way, either on a concrete pad or mounted on a pole, or can reside in a building. Our model recommends installing sufficient FDCs to support higher-than-anticipated levels of subscriber penetration and future growth potential. This approach will accommodate future subscriber growth with minimal re- engineering. Passive optical splitters are modular and can be added to an existing FDC as required to support subscriber growth, or to accommodate unanticipated changes to the fiber distribution network with potential future technologies.

Specifically, the proposed design model includes 20 secondary hubs consisting of environmentally-hardened equipment cabinets to house access-layer electronics, optical splitters, and related passive fiber optic termination materials. The proposed fiber backbone will provide diverse physical paths between all hub locations so that the only single points of failure in the network exist in the “last mile” physical plant between the subscribers and the nearest hub enclosure or shelter.

The distribution fiber cable plant downstream from each hub/FDC consists of feeder and access fiber. The feeder fiber generally provides connectivity between each FDC and multiple network access points (NAPs) located throughout the distribution plant, consisting of fiber splice enclosures and/or optical splitters. The access fiber generally consists of cable plant connecting individual customer fiber connections to these aggregation NAPs, and may include outdoor taps providing environmentally hardened connectors for customer drop cables.

The distribution and access network design proposed in this report is flexible and scalable enough to support two different electronics architectures:

1. Housing the core, distribution, and access network electronics centrally within the primary hubs, using only passive devices (optical splitters and patches) within each of the FDCs; or

2. Pushing the distribution and access network electronics further into the network by

housing them at the FDCs.

57

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

By housing all access network electronics only in primary hubs, the network would not require power at the individual FDCs. Choosing a network design that only supports this architecture may reduce certain implementation costs by allowing for smaller, passive FDCs in the field. However, this architecture will limit the redundancy capability from the FDCs to the hubs. By pushing the network electronics further into the field, the network gains added resiliency by allowing the access electronics to be fed from the redundant backbone network with automatic path protection switching to protect in the event of a fiber break. If backbone fiber is cut, the subscribers connected to a given FDC would still have network access.

Selecting a design that supports both of these models, as proposed, would allow HBPW to accommodate many years of shifting technology trends. In this case, the FDCs would be slightly larger, require electrical power connections, and contain active heat exchangers and backup battery systems (Figure 13), but would mitigate physical limitations to technology choices.

**Figure 13: Active FDC Example (Calix OD-2000)**

This design also increases the attractiveness of the FTTP infrastructure as a utility to facilitate access for competitive providers seeking to target specific market niches not served by HBPW, and requiring a limited initial investment in hardware of their own. The fiber rich design allows these providers to enter the market with a small deployment of network electronics (i.e., placing electronics only at the primary hub sites for a small number of customers), while allowing them to grow their network in response to demand by pushing electronics closer to their subscribers as capacity or particular service level requirements dictate.

58

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

In this model, we assume the use of Gigabit Passive Optical Network (GPON) electronics for the vast majority of HBPW subscribers, and Active Ethernet for a small percentage of subscribers (typically business customers) that request a premium service or require greater bandwidth. GPON is the most commonly provisioned FTTP service—used, for example, by Verizon (in its FiOS systems), Google Fiber, and Chattanooga EPB. Furthermore, we believe that this hybrid GPON- Active Ethernet architecture, particularly when coupled with the recommended physical architecture, will fully meet demand for the entire lifecycle of the initial hardware platform deployment of at least five to seven years.

Even with NG-PON2 hardware on the horizon and the recently announced XGS-PON standards promising to deliver 10 Gbps services over PON networks as early as 2017, we recommend GPON as the appropriate platform for its first generation of FTTP offerings—at least for the vast majority of its customers. XGS-PON is expected by some manufacturers to be introduced at price points approximately 30 percent to 40 percent higher than that of GPON for OLT, and potentially higher for the ONT hardware. The availability of XGS-PON is likely to push GPON hardware costs downward even further, thereby increasing its value position to serve the vast majority of HBPW customers when coupled with a flexible physical architecture supporting lower split ratios.

XGS-PON may offer a mechanism to introduce 10 Gbps services more widely, if demand warrants, as hardware becomes available. Manufacturers are already retooling existing product lines to support XGS-PON, and a single XGS-PON interface can be used to “feed” two or more “PONs”— meaning XGS-PON can be deployed on a 1:64 split basis overlaid on a network with GPON operating at a 1:32 or 1:16 split ratio, serving a limited number of 10 Gbps customers with reduced hardware costs.

NG-PON2 hardware will be significantly more expensive when it is available, and manufacturers have not begun to offer hard timelines for when it will be available for widespread consumption beyond limited trials. Eventually, even NG-PON2 hardware is likely to reach price points similar to today’s GPON hardware; while not recommended for HBPW in the near term, NG-PON2 demonstrates that the physical fiber infrastructure built now will support future generations of electronics providing capacity increases of many orders of magnitude.

Providers of gigabit services today typically provide these services on GPON platforms. Even though the GPON platform is limited to 1.24 Gbps upstream and 2.49 Gbps downstream for the subscribers connected to a single PON splitter, operators have found that the statistical variations in actual subscriber usage generally means that all subscribers can obtain 1 Gbps on a peak basis (without provisioned rate-limiting), even if the capacity is shared by multiple users in a PON.

Although peak demand by a given customer may spike to several hundred megabits per second, or even close to 1 Gbps (likely only when performing a speed test), providers have found recent

59

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

per customer average demand is closer to 1 Mbps even when the service is not rate limited. Even if we remove video services from the equation and assume upwards of 1 Gbps per PON is used continuously for on-demand and IP multicast video (more than three simultaneous 4K resolution video streams per customer in a 1:16 split), Neilson’s Law,65 which states that a high-end user's connection speed grows by 50 percent per year, suggests the demand presented by other applications and OTT services would not exceed GPON capacity until about 2025.

By casual observation of broadband speeds available over the past decade or two, Neilson’s Law seems to have proven fairly accurate—at least as far as can be expected of a prognostication tool based mostly on observation of market trends and technology development—and is still probably as good as any forecasting tool to conservatively assess capacity demand.

Even in networks providing “dedicated” connections, oversubscription occurs further upstream in the network—no Internet connection is truly “dedicated.” As discussed earlier, GPON manufacturers have a development roadmap to 10 Gbps and faster speeds as user demand increases beyond what GPON can support in the access layer, but these technologies will not be needed to support 1 Gbps service offerings until they are far more affordable many years from now.

GPON supports high-speed broadband data, and is easily leveraged by triple-play carriers for voice, video, and data services. The GPON OLT uses single-fiber (bi-directional) SFP modules to support multiple (most commonly 32) subscribers per PON. GPON uses passive optical splitting, which is performed inside fiber distribution cabinets (FDC), within the access network, or both, connecting fiber interfaces on the OLTs to the customer premises. In the proposed “home-run” access network architecture, all splitters are housed in the FDCs, each of which is equipped to support roughly 1,000 customers.

Active Ethernet (AE) provides a symmetrical (up/down) service that is commonly referred to as Symmetrical Gigabit Ethernet. AE can be provisioned to run at sub-gigabit speeds, and easily supports legacy voice (GR-303 and TR-008) and next-generation voice-over-IP (SIP and MGCP) services. For subscribers receiving Active Ethernet service, a single dedicated fiber connects between the subscriber premises and an access network Ethernet switch with no optical splitting. Because AE requires dedicated fiber (home-run) from the OLT to the CPE, and because each subscriber uses a dedicated SFP on the OLT, there is a significant equipment cost differential at the access layer to provision an AE subscriber versus a GPON subscriber. The recommended fiber plant design will provide Active Ethernet service or GPON service to all passings, enabling HBPW to select electronics based on the mix of services it plans to offer—and can modify or upgrade electronics to change the mix of services as demands grow. Furthermore, the recommended

65 https://www.nngroup.com/articles/law-of-bandwidth/

60

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

design entails the placement of equipment capable of providing a mix of both GPON and AE connections—managed and provisioned on a common platform, either from the same OLT line cards or by mixing different line cards in the same hardware chassis.

Attachment 5 provides a detailed bill of materials (BOM) for candidate network electronics, including OLT hardware and related components. We note that although our pricing is based on Calix hardware, several manufacturers, including Adtran and Alcatel-Lucent, can deliver competitive products meeting the recommended configurations.

**5.1.4 Customer Premises Equipment (CPE) and Service Drops** In the final segment of the recommended FTTP distribution plant, fiber runs from the FDC to subscriber taps located in the right-of-way near the customers’ homes and office buildings. The taps consist of factory assembled connector housings in which the fiber strands terminate. The service installer uses a pre-connectorized drop cable to connect the tap to the subscriber premises without the need for fiber optic splicing. The drop cable extends from the subscriber tap (either on the pole or underground) to the building, enters the building, and connects to customer premises equipment (CPE).

We have specified two CPE kits (residential and business) to offer various features and capabilities and to meet subscriber requirements, either of which can be provided in an indoor or outdoor configuration. Both consist primarily of an Optical Network Terminal (ONT) capable of either GPON or Ethernet media conversion (or both), providing copper-based (RJ-45) Gigabit Ethernet interfaces at the customer demarcation. The recommended design includes installation of an uninterruptible power supply (UPS) for each, and installation of at least one network cable drop within the home or business to connect to customer equipment.

Either CPE configuration can support symmetrical gigabit per second service rates, and include an integrated VoIP gateway to provide telephone services. The residential CPE configuration includes an Internet gateway with WiFi capabilities. The business CPE assumes the customer provides their own firewall or router at the service demarcation, but includes additional costs for more extensive indoor cabling and service provisioning support.

Attachment 5 provides a detailed bill of materials (BOM) for candidate network electronics, including the two CPE kits.

**5.2 FTTP Network Cost Estimates and Phasing** FTTP construction will entail costs in three basic categories:

• OSP labor and materials

• Network electronics

• Subscriber activation costs (service drop cables and CPE)

61

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

Our model assumes a mix of aerial and underground fiber construction, based on the prevailing mix of utilities in the City, and a 39.6 percent take rate. 66 Please note this take rate is only used as a placeholder for discussion in this section; as seen in the full financial analysis in Section 5, which shows the impact of take rate on construction cost, cash flow, and net income.

The estimated cost to construct the proposed FTTP OSP throughout the existing HBPW electric service footprint is approximately $44.4 million—which corresponds to a cost of approximately $1,540 per passing,67 not including drop cable installation, CPE, or network electronics. With an estimated $3.1 million in network electronics required, the total per passing cost increases to approximately $1,650.

With average per customer activation costs of just under $1,400, including CPE and drop cable installation, the total network implementation cost is estimated to be $63.2 million at a take rate of 39.6 percent. Table 11 summarizes the cost estimates.

66 Take rate is the percentage of subscribers who purchase services from an enterprise, and is a crucial driver in the success of an FTTP retail model. If the take rate is not met, the enterprise will not be able to sustain itself and its operational costs will have to be offset through some funding source to avoid allowing the enterprise to fail. 67 The model counts each potential residential or business customer as a passing, so single-unit buildings count as one passing, while each unit in a multi-dwelling or multi-business building is treated as a single passing.

62

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

**Table 11: Estimated FTTP Deployment Costs (Assuming a 39.6 Percent Take Rate)**

**Cost Component Total Estimated Cost**

**Backbone OSP Construction Costs**

**OSP Engineering** $ 6,180,000 **Quality Control/Quality Assurance** 3,285,000 **General OSP Construction Cost** 29,858,000 **Special Crossings** - **Backbone and Distribution Plant Splicing** 2,005,000 **Backbone Hub, Termination, and Testing** 3,111,000 ***Subtotal* $ 44,439,000**

**Backbone Network Electronics Costs**

**Core and Distribution Network Equipment** $ 738,000 **Access Equipment (GPON and Active Ethernet OLT)** 2,336,000 **Subtotal: $ 3,074,000**

**Subscriber Activation Costs**

**FTTP Service Drop and Lateral Installations** $ 9,340,000 **Customer Premises Equipment and Installation** 6,386,000 **Subtotal: $ 15,726,000**

**Total Estimated Cost: $ 63,239,000**

Figure 14 illustrates the total FTTP implementation costs as a function of the total initial take rate.

63

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

**Figure 14: Estimated FTTP Costs Are Take Rate-Dependent**

In the sections following, we describe our cost estimation methodology, and provide more detail on the estimated costs. We also discuss assumptions related to operating costs, and discuss implementation phasing considerations.

**5.2.1 OSP Cost Estimation Methodology and Assumptions** Reaching every residence and business within the HBPW electric service footprint will require building FTTP infrastructure along the vast majority of the nearly 450 miles of street miles. As with any utility, the design and associated costs for construction vary with the unique physical layout of the service area—no two streets are likely to have the exact same configuration of fiber optic cables, communications conduit, underground vaults, and utility pole attachments.

Costs are further varied by soil conditions, such as the prevalence of subsurface hard rock; the condition of utility poles and feasibility of “aerial” construction involving the attachment of fiber infrastructure to utility poles; and crossings of bridges, railways, and highways. Our estimation methodology involves the extrapolation of estimated costs on the basis of street mileage for strategically selected sample designs, as well as field surveys to ascertain unique attributes of particular service areas.

We first developed the system-level backbone network design, as described in the previous sections, to serve as the basis for subdividing the City into these smaller service areas. We then surveyed a broad sampling of the HBPW electric service area to estimate averages for key metrics impacting construction methodology and cost, such as requirements for special crossings (bridges, railways, etc.), the number of utility poles per mile, and the estimated level of utility

64

$47.5 $51.5 $55.5 $59.4 $63.4 $67.4 $71.3 $75.3 $79.3 $83.3 $87.2 $4.0 $14.0 $24.0 $34.0 $44.0 $54.0 $64.0 $74.0 $84.0 $94.0

0% 25% 50% 75% 100%

Total Cost ($M)

Take Rate (%)

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

pole make-ready construction required to facilitate aerial construction of fiber. This preliminary survey was performed via Google Earth Street View and supplied GIS data, allowing a large area to be surveyed cost effectively.

Our observations determined that there tend to be relatively large, contiguous subsections of the overall service area in which the electric utility infrastructure (as well as cable television in most cases) is almost entirely underground or aerial, and for which each can further be subdivided into areas having relatively consistent passing density (passings per street mile). As such, we delineated the entire service area on the basis of density and existing utility infrastructure type (aerial versus underground) according to the following seven categories:

• High density (>75 passings per street mile)

a. Aerial – 110 passings/mile on average b. Underground – 146 passings/mile on average c. Urban (downtown) Underground – 83 passings/mile on average

• Medium density (25 to 75 passings per street mile)

a. Aerial – 69 passings/mile on average b. Underground - 75 passings/mile on average

• Low density (<25 passings per street mile)

a. Aerial – 16 passings/mile on average b. Underground – 12 passings/mile on average

Attachment 6 provides a map that illustrates the delineations of the electric service area based on these categories.

We developed sample designs within each of the representative areas, selected to approximate the average density of passings per street mile for the entire category. These sample designs, coupled with key metrics derived through GIS analysis and surveys, were used to extrapolate quantities for corresponding labor and material units. Figure 15 below is a sample design illustrating each of the components of the distribution plant.

65

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

**Figure 15: Sample FTTP Distribution Layer Design**

The survey of existing OSP revealed certain key metrics related to aerial infrastructure that informed the cost estimate. In general, we believe aerial construction is viable as a cost savings alternative to underground construction along approximately 55 percent of the total network routes—those areas identified as aerial in Attachment 6. Within these areas, we expect no more than 20 percent of the poles will require significant make-ready work, consisting of 1.5 attachment relocations per pole on average, at an average cost of $150 each. Furthermore, we expect less than 5 percent of the poles in aerial areas will require replacement—note that we assume poles that have been “topped” represent ongoing pole renewal efforts not included in these estimates.

We also note that a significant number of residential areas are fed from pole lines located in rear easements, often made directly inaccessible by homeowners’ fences. We assume that HBPW has

66

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

appropriate polices and equipment in place to gain access and effect necessary make-ready work without significantly impacting costs.

Additional assumptions used to formulate our cost estimates based on input from HBPW staff include:

• Little or no hard rock will encountered during underground construction requiring special cutting or drilling equipment;

• Available space exists within existing conduit under special crossings (railroads, bridges, bodies of water, and highways) for new backbone cable to avoid new permitting and encroachment/licensing fees;

• Overhead crossings of private property requiring encroachment/licensing fees (i.e. railroad) can be overlashed without incurring new licensing fees; and

• Utility pole replacement, when required, will average approximately $1,000 per pole based on recent records.

**5.2.2 Fiber Construction Cost Estimates** The fiber construction cost estimates detailed below entail a turnkey implementation executed using contractor resources from design to acceptance testing. Backbone and distribution fiber plant implementation costs are estimated to be $44.4 million, not including service drops. At a take rate of 39.6 percent, we estimate fiber service drop connections costing an additional $9.3 million (just under $820 per drop on average), yielding a total OSP cost of approximately $53.8 million.

Our estimates assume the 45 mile backbone can be constructed primarily along existing fiber routes, or routes required for distribution plant to serve new customers, consisting of a new 288- strand cable. Only 2.2 miles of the backbone are anticipated to occur over standalone paths. Additional cost savings may be possible if sufficient spare strand capacity is available along existing fiber routes; certainly timeframes can be reduced for activating particular service areas where backbone need not be constructed. However, to maximize flexibility of the backbone, we include this dedicated capacity even along existing fiber routes.

Cost estimates assume the installation of 2-inch flexible HDPE conduit using horizontal directional drilling along all underground routes (two 2-inch conduits along underground backbone routes). Cost estimates are inclusive of all project management, quality assurance, engineering, permitting, materials, and labor anticipated, including permanent hard surface restoration, traffic control, and work area protection. Table 12 provides details OSP construction costs, broken down by key line items and passing density.

67

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

**Table 12: FTTP OSP Construction Cost Estimates**

**Cost Component**

68 **Phase 1 Phase 2 Phase 3 Phase 4 Total Backbone High Density**

(> 75 passings/mi)

**Medium Density** (25-75 passings/mi)

**Low Density** (< 25 passings/mi)

**Estimated Cost Backbone OSP Construction Costs OSP Engineering** $29,000 $741,000 $4,449,000 $961,000 $6,180,000 **Quality Control/Quality Assurance**

$15,000 $394,000 $2,365,000 $511,000 $3,285,000

**General OSP Construction Cost**

$1,138,000 $3,210,000 $21,229,000 $4,281,000 $29,858,000

**Special Crossings** $ – $ – $ – $ – $ – **Backbone and Distribution Plant Splicing**

$4,000 $251,000 $1,575,000 $175,000 $2,005,000

**Backbone Hub, Termination, and Testing**

$1,498,000 $277,000 $1,150,000 $186,000 $3,111,000

***Subtotal* $ 44,390,000**

**Subscriber Activation Costs FTTP Service Drop and Lateral Installations**

$ – $1,257,000 $7,151,000 $932,000 $9,340,000

**Subtotal: $9,340,000 Total Estimated**

**Cost:** $2,684,000 $6,130,000 $37,919,000 $7,046,000 $53,779,000 **Total Estimated**

**Passings: N/A 5,678 21,977 1,199 28,854**

A more detailed breakdown of the OSP costs is included in Attachment 4. The cost components itemized in the table above include the following scope of tasks:

• ***Engineering*** *–* includes system level architecture planning, preliminary designs and field walk-outs to determine candidate fiber routing; development of detailed engineering prints and preparation of permit applications; and post-construction “as-built” revisions to engineering design materials.

• ***Quality Control / Quality Assurance*** – includes expert quality assurance field review of final construction for acceptance.

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

• ***General OSP Construction*** – consists of all labor and materials related to “typical” underground or aerial OSP construction, including conduit placement, utility pole make- ready construction, aerial strand installation, fiber installation, and surface restoration; includes all work area protection and traffic control measures inherent to all roadway construction activities.

• ***Special Crossings*** – consists of specialized engineering, permitting, and incremental construction (material and labor) costs associated with crossings of railroads, bridges, and interstate / controlled access highways.

• ***Backbone and Distribution Plant Splicing*** – includes all labor related to fiber splicing of outdoor fiber optic cables.

• ***Backbone Hub, Termination, and Testing*** – consists of the material and labor costs of placing hub shelters and enclosures, terminating backbone fiber cables within the hubs, and testing backbone cables.

• ***FTTP Service Drop and Lateral Installations –*** consists of all costs related to fiber service drop installation, including OSP construction on private property, building penetration, and inside plant construction to a typical backbone network service “demarcation” point; also includes all materials and labor related to the termination of fiber cables at the demarcation point. A take rate of 35 percent was assumed for standard fiber service drops.

The following table provides estimated OSP construction costs broken down based on areas of defined passing density with and without service drop costs, illustrating the range of relative costs per passing for different types of service areas.

**Phase**

69 **Distribution**

**Cost Plant Mileage**

**per Total (with drops) Cost**

**(without Total Cost**

**drops) Passings**

**(Distribution Passing**

**Only)**

**Cost Per Plant Mile (Distribution Only)**

Total: 475 53,779,704 $44,439,766 28,854 $1,540 $90,000

Backbone 2.2 $2,685,137 $2,685,137 – N/A $1,208,037 High Density 56.9 $6,130,228 $4,873,389 5,678 $858 $85,604 Med. Density 341.7 $37,917,982 $30,767,229 21,977 $1,400 $90,042 Low Density 73.8 $7,046,356 $6,114,012 1,199 $5,099 $82,836

Where applicable, cost estimates are based on contract labor and material rates we have seen in other competitively bid fiber projects, as well as supplied HBPW contractor rates.

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

**5.2.3 Network Electronics Cost Estimates** Core, distribution, and access layer network electronics are estimated at a total cost of approximately $3.1 million, not including CPE. An additional cost for CPE of $6.4 million at a take rate of 39.6 percent yields a total network electronics cost of $9.5 million. All cost estimates include estimated installation and integration costs. Table 13 provides estimated network electronics costs, broken down by project “phases” corresponding to areas of defined passing density.

**Table 13: FTTP Network Electronics Cost Estimate**

**Cost Component**

70 **Phase 1 Phase 2 Phase 3 Phase 4 Backbone High Density**

(> 75 passings/mi)

**Medium Density** (25-75

**Total Estimated Cost** passings/mi)

**Low Density** (< 25 passings/mi)

**Backbone Network Electronics Costs Core and Distribution Network Equipment**

$ 738,000 $ – $ – $ – $ 738,000

**Access Equipment (GPON and Active Ethernet OLT)**

$ – $483,000 $1,732,000 $121,000 $2,336,000

**Subtotal: $3,074,000**

**Subscriber Activation Costs Customer Premises Equipment and Installation**

$ – $1,257,000 $4,864,000 $265,000 $6,386,000

**Subtotal: $ 6,386,000 Total Estimated**

**Cost:** $738,000 $1,740,000 $6,596,000 $386,000 **$9,460,000**

CPE equipment and installation costs are estimated at approximately $530 for a standard residential subscriber and $700 for a business subscriber, both inclusive of onsite configuration of the CPE, installation of an uninterruptible power supply (UPS), and installation of at least one network cable drop within the home or business to connect to customer equipment.

We note that the HBPW operates an existing Ethernet backbone comprised of Alcatel-Lucent 7210 Service Access Switches (SAS), interconnected in a topology of multiple rings operating at 10 Gbps speeds. While it may be possible to leverage this backbone for the near term in place of certain core and distribution network electronics included in our cost estimates, we expect that

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

the useful lifespan of this hardware and capacity demands will require upgrades to hardware supporting dense aggregation of 10 GE connections within the timeframe of the initial FTTP network buildout.

Attachment 5 provides a detailed bill of materials (BOM) for a candidate network electronics supporting an FTTP deployment throughout the HBPW electric service area.

**5.2.4 Network Maintenance Costs** Fiber optic cable is resilient compared to copper telephone lines and cable TV coaxial cable. The fiber itself does not corrode, and fiber cable installed over 30 years ago is still in good condition. However, fiber can be vulnerable to accidental cuts by unrelated construction, traffic accidents, and severe weather. One of the larger costs associated with OSP maintenance are associated with performing locates for underground plant in response to locate requests initiated through the state-mandated one-call “811” damage prevention system (i.e. the MISS DIG System).

Costs associated with maintenance and repair can be highly variable on a year-to-year basis, particularly for required undergrounding, relocations due to new construction conflicts, and fiber breaks - but over time these costs trend towards averages we have seen in networks of varying size. In particular, we recommend planning for expenses associated with OSP maintenance of approximately 1 percent of the total construction cost, or approximately $540,000 for the full network. Included within this figure is an estimated fiber break per year for every 10 miles of plant, with repair costs ranging from $5,000 to $10,000 per incident.

An estimated $380,000 annually is required for network electronics maintenance. This covers a range of strategies entailing a mix of manufacturer maintenance contracts and warehousing spare components. In general, the level of equipment redundancy provided by the recommended architecture eliminates the need for maintenance contracts that provide rapid, advanced replacement of failed hardware. Instead, our estimates include costs for maintenance contracts providing next business day replacement of failed components for the core and distribution layers of the network, as well as an annual budgetary estimate equivalent to 15 percent of the total cost of access layer equipment to cover spares, replacements, and/or equivalent maintenance contracts.

**5.2.5 Implementation Phasing Considerations** The cost estimates generated for this analysis reveal potentially significant details to guide a cost- effective FTTP deployment that maximizes return on investment, and perhaps more importantly, offers insights into how to phase construction to capture new revenues with the least amount of new investment. Market demand and other factors impacting take rate notwithstanding, per passing OSP construction costs will play a significant role in the business case for an FTTP deployment.

71

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

An initial focus on FTTP deployment within the boundaries of the City of Holland, for example, provides a substantial reduction in per passing cost without necessitating any deviation in the recommended architecture. Serving an estimated 15,654 passings (based on electric service drop GIS data), the total estimated FTTP implementation cost is $29.8 million with a take rate of 39.6 percent. This encompasses per passing costs of approximately $1,420, including electronics (but not including subscriber activation costs), compared to $1,650 per passing for the full deployment throughout the entire electric service area.

For sake of comparison, Table 14 details the full FTTP implementation costs for a deployment limited to City of Holland boundaries, including subscriber activation costs at a take rate of 39.6 percent.

72

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

**Table 14: Estimated FTTP Deployment Costs Within City of Holland Boundaries (Assuming a 39.6 Percent Take Rate)**

**Cost Component**

73 **Phase 1 Phase 2 Phase 3 Phase 4 Total Backbone High Density**

(> 75 passings/mi)

**Medium Density** (25-75 passings/mi)

**Low Density**

**Estimated** (< 25 passings/mi) **Cost Backbone OSP Construction Costs OSP Engineering** $29,000 $689,000 $1,801,000 $362,000 $2,881,000 **Quality Control/Quality Assurance**

$15,000 $366,000 $957,000 $193,000 $1,531,000

**General OSP Construction Cost**

$684,000 $2,776,000 $7,714,000 $1,976,000 $13,152,000

**Special Crossings** $ – $ – $ – $ – $ – **Backbone and Distribution Plant Splicing**

$2,000 $219,000 $639,000 $67,000 $927,000

**Backbone Hub, Termination, and Testing**

$1,030,000 $207,000 $440,000 $71,000 $1,748,000

***Subtotal:* $20,239,000**

**Backbone Network Electronics Costs Core Network Equipment** $667,000 $ – $ – $ – $667,000 **Distribution and Access Equipment (GPON OLT)**

$ – $483,000 $846,000 $40,000 $1,369,000

**Subtotal: $2,036,000**

**Subscriber Activation Costs FTTP Service Drop and Lateral Installations**

$ – $942,000 $2,844,000 $230,000 $4,016,000

**Customer Premises Equipment and Installation**

$ – $1,085,000 $2,299,000 $81,000 $3,465,000

**Subtotal: $7,481,000 Total Estimated**

**Cost:** $2,427,000 $6,767,000 $17,540,000 $3,020,000 **$29,756,000 Total Estimated**

**Passings: N/A 4,901 10,387 366 15,654**

FTTP Deployment Cost and Financial Projections| *March 2016* Draft

Without limiting the deployment to a particular political boundary, consideration should be given to density and construction type delineations when determining project phasing. HBPW can minimize risk and maximize the potential to reach its entire service area with FTTP through a strategic approach to project phasing. Indeed, high-density and medium-density aerial construction areas will tend to provide the best mix of cost per passing and reduced time to market of FTTP services given the particular construction environment throughout the HBPW electric service footprint. Not including the backbone, these areas represent less than 44 percent of the estimated total distribution plant costs (not including drops), but reach almost 57 percent of the total potential passings.

Outside of particular economic development benefits, or potentially the ability to reach customers with particularly high capacity demands, the low-density areas should constitute longer-term targets, in general. Throughout the electric service area, the low-density areas represent nearly 15 percent of the total distribution plant costs (not including service drops), but only 4 percent of the total passings. Investments in these areas may need to be examined on a case-by-case basis with respect to serving particular customers.

74