

Appendix E

Prepared by



55 East Monroe Street
Chicago, IL 60603-5780 USA

Integrated Resource Plan Engineering Study Technical Assessment

Prepared for
NIPSCO

Report SL-012949

Project 12749-842
November 2015

F I N A L

Integrated Resource Plan Engineering Study Technical Assessment

Prepared for



SL-012949
November 2015



55 East Monroe Street
Chicago, IL 60603-5780 USA

Integrated Resource Plan Engineering Study Technical Assessment

Prepared by	Joseph Hudziak	Senior Consultant (Fossil Fuel & Biomass)
	Carl Jakubowski	Senior Consultant (Nuclear)
	Joe Capadona	Senior Consultant (Wind)
	David Jong	Senior Consultant (Distributed Generation & Energy Storage)
	Jose Mayen	Senior Consultant (Electric Grid Reliability)
	John Wroble	Senior Consultant (Capital & O&M)
	Dave Helm	Technical Consultant (Emissions)
	Ken Snell	Technical Consultant (Environmental Regulations)
	Jeffery Cobb	Technical Consultant (Natural Gas)
	Emile Jabre	Technical Consultant (Solar and Geothermal)
	Tony Song	Technical Consultant (Battery Storage)
	Ben Edgar	President, White Harvest Energy (CHP & Microgrids)

Reviewed by William D. Edgar
William D. Edgar
Senior Management
Consultant

Approved by Christopher D. Ungate November 20, 2015
Christopher Ungate
Senior Principal
Management Consultant
Date

SL-012949
November 2015



LEGAL NOTICE

This report was prepared by Sargent & Lundy, L.L.C. (“S&L”), expressly for the sole use of Northern Indiana Public Service Company (“NIPSCO”) in accordance with the agreement between S&L and NIPSCO. This report was prepared using the degree of skill and care ordinarily exercised by engineers practicing under similar circumstances. The information and data contained in this report are time sensitive and changes in the data, applicable codes, standards, and acceptable engineering practices may invalidate the findings of this report. Any use or reliance upon this report by third parties shall be at their sole risk.



NIPSCO Integrated Resource Plan Engineering Study Technical Assessment

CONTENTS

<u>Section</u>	<u>Page</u>
1. EXECUTIVE SUMMARY	1
1.1 Project Introduction.....	1
1.2 Environmental Requirements.....	3
1.3 Cost and Performance Methodology.....	5
1.4 Cost and Performance Results.....	5
1.4.1 Simple Cycle Natural Gas Technologies.....	5
1.4.2 Combined Cycle Natural Gas Technologies	6
1.4.3 Black Start Retrofit for Schahfer Unit 16B	8
1.4.4 Coal to Natural Gas Boiler Conversions at Schahfer	8
1.4.5 Coal and Nuclear Technologies	9
1.4.6 Renewable Technologies.....	11
1.4.7 Energy Storage Technologies.....	13
1.4.8 Distributed Generation Technologies.....	15
1.4.9 Grid Reliability Enhancements	17
2. INTRODUCTION.....	18
3. STUDY BASIS AND ASSUMPTIONS	19
3.1 Scope Basis	19
3.2 Impact of Environmental Requirements	22
3.2.1 Introduction	22
3.2.2 Air Quality Regulations	22
3.2.3 Indiana Water Quality Regulation.....	48
3.2.4 Solid Waste Regulations	53
3.2.5 Summary of Potential Environmental Control Technology Requirements.....	54
3.3 General Assumptions	57
3.3.1 General Assumptions for Natural Gas Technologies	57
3.3.2 Simple-Cycle Aeroderivative Combustion Turbine Assumptions	59
3.3.3 Simple-Cycle Frame Combustion Turbine Assumptions.....	61



CONTENTS (cont.)

<u>Section</u>	<u>Page</u>
3.3.4 Combined-Cycle Frame Combustion Turbine Assumptions	63
3.3.5 Brownfield Assumptions for Combustion Turbine Options	65
3.3.6 Combined-Cycle Combustion Turbine Repowering of Bailly Unit 7 Assumptions	66
3.3.7 Combined-Cycle Conversion of Schahfer Units 16A & B Assumptions	68
3.3.8 Combined-Cycle Conversion of Generic Two-Unit Simple-Cycle Assumptions	71
3.3.9 Coal to Natural Gas Boiler Conversion Assumptions	73
3.3.10 Ultra-Supercritical Pulverized Coal Assumptions	76
3.3.11 Advanced Circulating Fluidized Bed Coal Boiler Assumptions	78
3.3.12 Integrated Gasification Combined Cycle Assumptions	80
3.3.13 Biomass Boiler Assumptions	82
3.4 Assumptions Matrix	83
3.5 Performance Parameters	84
3.6 Capital Cost Methodology	87
3.6.1 Project Direct Costs	87
3.6.2 Project Indirect Costs	88
3.6.3 Owner Direct Costs	88
3.6.4 Owner Indirect Costs	91
3.7 Capital Cost Exclusions	92
3.7.1 Allowance for Funds Used During Construction	92
3.7.2 CO2 Transportation Pipeline Costs	92
3.7.3 Other Costs	92
3.8 Operating Cost Methodology	93
3.9 Milestone Schedule and Cash Flows	94
4. NATURAL GAS TECHNOLOGIES	95
4.1 Simple-Cycle Gas-Fired Combustion Turbine	95
4.1.1 Description – Simple-Cycle CT	95
4.1.2 Performance – Simple-Cycle CT	96
4.1.3 Emission Controls – Simple-Cycle CT	98
4.1.4 Waste Disposal – Simple-Cycle CT	100
4.1.5 Capital Cost – Simple-Cycle CT	101
4.1.6 O&M Cost – Simple-Cycle CT	103
4.1.7 Milestone Schedule and Cash Flows – Simple-Cycle CT	105
4.1.8 Scheduled Maintenance – Simple-Cycle CT	106



CONTENTS (cont.)

<u>Section</u>	<u>Page</u>
4.2 Combined-Cycle Gas-Fired Frame Combustion Turbine	108
4.2.1 Description – Combined-Cycle Frame CT.....	108
4.2.2 Performance – Combined-Cycle Frame CT.....	110
4.2.3 Emission Controls – Combined-Cycle Frame CT.....	112
4.2.4 Waste Disposal – Combined-Cycle Frame CT	115
4.2.5 Capital Cost – Combined-Cycle Frame CT	116
4.2.6 O&M Cost – Combined-Cycle Frame CT	118
4.2.7 Milestone Schedule and Cash Flows – Combined-Cycle Frame CT	120
4.2.8 Scheduled Maintenance – Combined-Cycle Frame CT	121
4.3 Black Start Retrofit for Gas-Fired Schahfer Unit 16B	122
4.3.1 Description – Black Start Retrofit at Schahfer Unit 16B	122
4.3.2 Performance – Black Start Retrofit at Schahfer Unit 16B	122
4.3.3 Emission Controls – Black Start Retrofit at Schahfer Unit 16B	122
4.3.4 Waste Disposal – Black Start Retrofit at Schahfer Unit 16B.....	123
4.3.5 Capital Cost – Black Start Retrofit at Schahfer Unit 16B	123
4.4 Coal to Natural Gas Boiler Conversions at Schahfer Station.....	124
4.4.1 Description – Coal to Gas Conversions	124
4.4.2 Performance – Coal to Gas Conversions.....	131
4.4.3 Emission Controls – Coal to Gas Conversions	133
4.4.4 Waste Disposal – Coal to Gas Conversions	138
4.4.5 Capital Cost – Coal to Gas Conversions	139
4.4.6 O&M Cost – Coal to Gas Conversions	141
4.4.7 Milestone Schedule and Cash Flows – Coal to Gas Conversions	143
4.4.8 Scheduled Maintenance – Coal to Gas Conversions.....	144
5. COAL AND NUCLEAR TECHNOLOGIES	145
5.1 Coal	145
5.1.1 Description – Coal.....	145
5.1.2 Performance – Coal.....	147
5.1.3 Emission Controls – Coal.....	149
5.1.4 Waste Disposal – Coal	151
5.1.5 Capital Cost – Coal	152
5.1.6 O&M Cost – Coal	154
5.1.7 Milestone Schedule and Cash Flows – Coal	156
5.1.8 Scheduled Maintenance – Coal	157
5.2 Integrated Gasification Combined Cycle	158



CONTENTS (cont.)

<u>Section</u>	<u>Page</u>
5.2.1 Description – IGCC.....	158
5.2.2 Performance – IGCC.....	159
5.2.3 Emission Controls – IGCC.....	161
5.2.4 Waste Disposal – IGCC	163
5.2.5 Capital Cost – IGCC	164
5.2.6 O&M Cost – IGCC	167
5.2.7 Milestone Schedule and Cash Flows – IGCC	169
5.2.8 Scheduled Maintenance – IGCC	170
5.3 Nuclear	171
5.3.1 Description – Nuclear.....	171
5.3.2 Performance – Nuclear.....	178
5.3.3 Emission Controls – Nuclear.....	180
5.3.4 Waste Disposal – Nuclear	180
5.3.5 Capital Cost – Nuclear	181
5.3.6 O&M Cost – Nuclear	183
5.3.7 Milestone Schedule and Cash Flows – Nuclear	185
5.3.8 Scheduled Maintenance – Nuclear	186
6. RENEWABLE TECHNOLOGIES	187
6.1 Biomass.....	187
6.1.1 Description – Biomass	187
6.1.2 Performance – Biomass.....	187
6.1.3 Emission Controls – Biomass	189
6.1.4 Waste Disposal – Biomass	191
6.1.5 Capital Cost – Biomass	192
6.1.6 O&M Cost – Biomass	194
6.1.7 Milestone Schedule and Cash Flows – Biomass	196
6.1.8 Scheduled Maintenance – Biomass.....	197
6.2 Onshore and Offshore Wind	198
6.2.1 Description – Wind	198
6.2.2 Performance – Wind.....	206
6.2.3 Emission Controls – Wind	208
6.2.4 Waste Disposal – Wind	208
6.2.5 Capital Cost – Wind	208
6.2.6 O&M Cost – Wind	210
6.2.7 Milestone Schedule and Cash Flows – Wind.....	212



CONTENTS (cont.)

<u>Section</u>	<u>Page</u>
6.2.8 Scheduled Maintenance – Wind.....	213
6.3 Concentrated Solar Power.....	215
6.3.1 Description – Concentrated Solar Power	215
6.3.2 Justification for Exclusion – Concentrated Solar Power	215
6.4 Solar Photovoltaic	218
6.4.1 Description – Solar Photovoltaic.....	218
6.4.2 Performance – Solar Photovoltaic.....	220
6.4.3 Emission Controls – Solar Photovoltaic.....	222
6.4.4 Waste Disposal – Solar Photovoltaic	222
6.4.5 Capital Cost – Solar Photovoltaic	222
6.4.6 O&M Cost – Solar Photovoltaic	224
6.4.7 Milestone Schedule and Cash Flows – Solar Photovoltaic	226
6.4.8 Scheduled Maintenance – Solar Photovoltaic	227
6.5 Geothermal.....	228
6.5.1 Description – Geothermal	228
6.5.2 Justification for Exclusion – Geothermal.....	228
7. ENERGY STORAGE TECHNOLOGIES.....	231
7.1 Energy Storage.....	231
7.1.1 Description – Pumped Storage	231
7.1.2 Justification for Exclusion – Pumped Storage	233
7.1.3 Description – Compressed Air	236
7.1.4 Justification for Exclusion – Compressed Air.....	238
7.1.5 Description – Liquefied Air	241
7.1.6 Justification for Exclusion – Liquefied Air.....	241
7.2 Battery Storage.....	242
7.2.1 Description – Battery Storage	242
7.2.2 Performance – Battery Storage	244
7.2.3 Emission Controls – Battery Storage	246
7.2.4 Waste Disposal – Battery Storage.....	246
7.2.5 Capital Cost – Battery Storage	246
7.2.6 O&M Cost – Battery Storage.....	248
7.2.7 Milestone Schedule and Cash Flows – Battery Storage.....	250
7.2.8 Scheduled Maintenance – Battery Storage.....	251



CONTENTS (cont.)

<u>Section</u>	<u>Page</u>
8. DISTRIBUTED GENERATION TECHNOLOGIES.....	252
8.1 Distributed Generation	252
8.1.1 Description – Distributed Generation.....	252
8.1.2 Performance – Distributed Generation.....	268
8.1.3 Emission Controls – Distributed Generation.....	270
8.1.4 Waste Disposal – Distributed Generation	272
8.1.5 Capital Cost – Distributed Generation	273
8.1.6 O&M Cost – Distributed Generation	274
8.1.7 Milestone Schedule and Cash Flows – Distributed Generation	276
8.1.8 Scheduled Maintenance – Distributed Generation	277
8.2 Combined Heat and Power.....	278
8.2.1 Description – Combined Heat and Power	278
8.2.2 Market Penetration – Combined Heat and Power	280
8.2.3 Implementation – Combined Heat and Power	283
8.2.4 Operations – Combined Heat and Power	284
8.3 Microgrids	286
8.3.1 Description – Microgrids	286
8.3.2 Market Penetration – Microgrids	287
8.3.3 Implementation – Microgrids.....	289
8.3.4 Operations – Microgrids.....	291
9. GRID RELIABILITY ENHANCEMENTS.....	292
9.1 Interconnection Upgrades for Distributed Generation	292
9.1.1 Description – Interconnection Upgrades.....	292
9.1.2 Market Penetration – Interconnection Upgrades.....	300
9.1.3 Implementation – Interconnection Upgrades	300
9.1.4 Operations – Interconnection Upgrades	301
9.2 Volt/VAR Optimization and Sensors	303
9.2.1 Description – Volt/VAR Optimization	303
9.2.2 Market Penetration – Volt/VAR Optimization	303
9.2.3 Implementation – Volt/VAR Optimization.....	304
9.2.4 Operations – Volt/VAR Optimization.....	304
10. WORKS CITED	306



CONTENTS (cont.)

Section

Page

Appendixes

- A. Distributed Generation Screening Analysis Results
- B. Cost and Performance Details



TABLES AND FIGURES

<u>Table or Figure</u>	<u>Page</u>
Table 1-1 — Air Quality Control Technology and Cooling System Requirements Summary	3
Table 1-2 — Executive Summary Results for Simple Cycle Natural Gas Technologies	6
Table 1-3 — Executive Summary Results for Combined Cycle Natural Gas Technologies	7
Table 1-4 — Executive Summary Results for Coal to Natural Gas Boiler Conversions.....	9
Table 1-5 — Executive Summary Results for Coal and Nuclear Technologies	10
Table 1-6 — Executive Summary Results for Renewable Technologies	12
Table 1-7 — Executive Summary Results for Battery Storage Technologies	14
Table 1-8 — Executive Summary Results for Distributed Generation Technologies	16
Table 3-1 — Distributed Generation Screening Analysis Criteria.....	21
Table 3-2 — Pertinent New Source Performance Standards	23
Table 3-3 — Electric Utility Steam Generating Units NSPS Emission Standards	24
Table 3-4 — Industrial-Commercial-Institutional Steam Generating Units NSPS Emission Standards.....	25
Table 3-5 — Combustion Turbine NSPS NOx Emission Standards	27
Table 3-6 — Standards of Performance for Steam Generating Units and IGCC Units	29
Table 3-7 — Standards of Performance for Stationary Combustion Turbines	30
Table 3-8 — Pertinent Stationary Source NESHAPs	33
Table 3-9 — New Coal-Fired Electric Utility Steam Generating Units with FGD NESHAP Emission Limits...	34
Table 3-10 — Industrial, Commercial, and Institutional Boilers and Process Heaters NESHAP Limits for New Major Source Fluidized Bed Biomass-Fired Unit.....	35
Table 3-11 — ICI Boilers and Process Heaters NESHAP FPM Limits for New Fluidized Bed Biomass-Fired Units at Area Sources.....	36
Table 3-12 — Offset Ratio Requirements for Major Stationary Sources	41
Table 3-13 — PSD Significant Emissions Thresholds in Indiana	41
Table 3-14 — Potential BACT Requirements for Coal-Fired Boilers.....	44
Table 3-15 — Potential BACT Requirements for IGCC	45
Table 3-16 — Potential BACT Requirements for Natural Gas-Fired Simple- and Combined-Cycle Combustion Turbines.....	46
Table 3-17 — Potential BACT Requirements for Biomass-Fired Boiler	47
Table 3-18 — Effluent Limitation Guidelines	51
Table 3-19 — Air Quality Control Technology and Cooling System Requirements Summary.....	55



TABLES AND FIGURES (cont.)

<u>Table or Figure</u>	<u>Page</u>
Table 3-20 — Gas-Fired Technology Assumptions.....	58
Table 3-21 — Simple-Cycle Gas-Fired Aeroderivative CT Configuration Assumptions	59
Table 3-22 — Simple-Cycle Aeroderivative CT Performance Assumptions	60
Table 3-23 — Simple-Cycle Gas-Fired Frame CT Configuration Assumptions	61
Table 3-24 — Simple-Cycle Frame CT Performance Assumptions.....	62
Table 3-25 — Combined-Cycle Gas-Fired CT Configuration Assumptions.....	63
Table 3-26 — Combined-Cycle Frame CT Performance Assumptions.....	64
Table 3-27 — Gas-Fired CT Brownfield Configuration Assumptions.....	65
Table 3-28 — Bailly Unit 7 Combined-Cycle Repowering Configuration Assumptions.....	66
Table 3-29 — Bailly Unit 7 Combined-Cycle Repowering Performance Assumptions.....	67
Table 3-30 — Schahfer Units 16A & B Combined-Cycle Conversion Configuration Assumptions	69
Table 3-31 — Schahfer Units 16A & B Combined-Cycle Conversion Performance Assumptions	70
Table 3-32 — Generic Simple- to Combined-Cycle Conversion Configuration Assumptions	71
Table 3-33 — Generic Simple- to Combined-Cycle Conversion Performance Assumptions	72
Table 3-34 — Coal to Natural Gas Boiler Technical Challenges	74
Table 3-35 — Coal to Natural Gas Boiler Conversion Assumptions	75
Table 3-36 — Ultra-Supercritical Pulverized Coal Configuration Assumptions.....	77
Table 3-37 — Ultra-Supercritical Pulverized Coal Performance Assumptions.....	77
Table 3-38 — Advanced CFB Coal Configuration Assumptions.....	79
Table 3-39 — Advanced CFB Coal Performance Assumptions.....	79
Table 3-40 — IGCC Configuration Assumptions.....	81
Table 3-41 — IGCC Performance Assumptions.....	81
Table 3-42 — Biomass Boiler Configuration Assumptions	82
Table 3-43 — Biomass Boiler Performance Assumptions	82
Table 3-44 — Assumptions Matrix.....	83
Table 3-45 — Performance Parameters for Selected Technologies.....	84
Table 3-46 — Generic Capital Cost Assumptions	87
Table 3-47 — Electric Interconnection Capital Cost Assumptions	89
Table 3-48 — Gas Interconnection Capital Cost Assumptions	90



TABLES AND FIGURES (cont.)

<u>Table or Figure</u>	<u>Page</u>
Table 3-49 — Operating Cost Assumptions	94
Table 4-1 — Simple-Cycle Performance Data.....	97
Table 4-2 — Simple-Cycle Emissions Data	99
Table 4-3 — Simple-Cycle Gas Turbine Capital Cost Data	102
Table 4-4 — Simple-Cycle Gas Turbine Operating Cost Data.....	104
Table 4-5 — Simple-Cycle Gas Turbine Development Schedule.....	105
Table 4-6 — Typical Maintenance Schedule for Aeroderivative Turbines	106
Table 4-7 — Typical Maintenance Schedule for Frame Turbines	107
Table 4-8 — Combined-Cycle Performance Data	111
Table 4-9 — Combined-Cycle Emissions Data	113
Table 4-10 — Combined Cycle Gas Turbine Capital Cost Data	117
Table 4-11 — Combined-Cycle Gas Turbine Operating Cost Data	119
Table 4-12 — Combined-Cycle Gas Turbine Development Schedule	120
Table 4-13 — Typical Maintenance Schedule for Combined Cycle	121
Table 4-14 — Common Transient Conditions to Evaluate.....	127
Table 4-15 — Coal-to-Gas Conversion Performance Data.....	132
Table 4-16 — Coal-to-Gas Conversion Emissions Data.....	137
Table 4-17 — Coal-to-Gas Conversion Capital Cost Data	140
Table 4-18 — Coal-to-Gas Conversion Operating Cost Data.....	142
Table 4-19 — Coal-to-Gas Conversion Development Schedule	143
Table 5-1 — Coal Performance Data.....	148
Table 5-2 — Coal Emissions Data.....	150
Table 5-3 — Coal Capital Cost Data	153
Table 5-4 — Coal Operating Cost Data.....	155
Table 5-5 — Coal Development Schedule.....	156
Table 5-6 — IGCC Performance Data.....	160
Table 5-7 — IGCC Emissions Data.....	162
Table 5-8 — IGCC Capital Cost Data	166
Table 5-9 — IGCC Operating Cost Data.....	168



TABLES AND FIGURES (cont.)

<u>Table or Figure</u>	<u>Page</u>
Table 5-10 — IGCC Development Schedule.....	169
Table 5-11 — Status of Proposed Nuclear Plants	174
Table 5-12 — AP1000 Plant Designs Under Construction.....	176
Table 5-13 — Nuclear Performance Data.....	179
Table 5-14 — Nuclear Capital Cost Data	182
Table 5-15 — Nuclear Operating Cost Data.....	184
Table 5-16 — Nuclear Development Schedule.....	185
Table 6-1 — Biomass Performance Data.....	188
Table 6-2 — Biomass Emissions Data.....	190
Table 6-3 — Biomass Capital Cost Data	193
Table 6-4 — Biomass Operating Cost Data.....	195
Table 6-5 — Biomass Development Schedule.....	196
Table 6-6 — Wind Farms in Northern Indiana	199
Table 6-7 — Advantages and Disadvantages of Wind Power	200
Table 6-8 — Summary of Northern Indiana Annual Wind Speed (m/s)	202
Table 6-9 — Wind Technology Performance Data.....	207
Table 6-10 — Wind Technology Capital Cost Data	209
Table 6-11 — Wind Technology Operating Cost Data.....	211
Table 6-12 — Wind Technology Development Schedule	212
Table 6-13 — Solar PV Technology Performance Data.....	221
Table 6-14 — Solar PV Technology Capital Cost Data	223
Table 6-15 — Solar PV Technology Operating Cost Data.....	225
Table 6-16 — Solar PV Technology Development Schedule.....	226
Table 7-1 — Pumped Storage Facilities	234
Table 7-2 — Battery Storage Performance Data.....	245
Table 7-3 — Battery Storage Capital Cost Data	247
Table 7-4 — Battery Storage Operating Cost Data.....	249
Table 7-5 — Battery Storage Development Schedule	250
Table 8-1 — FIT Changes (Phase I to Phase II)	254



TABLES AND FIGURES (cont.)

<u>Table or Figure</u>	<u>Page</u>
Table 8-2 — USDA REAP Wind Funding and Awards, 2003 – 2014	267
Table 8-3 — Distributed Generation Performance Data	269
Table 8-4 — Distributed Generation Emissions Data	271
Table 8-5 — Distributed Generation Capital Cost Data	273
Table 8-6 — Distributed Generation Operating Cost Data	275
Table 8-7 — Distributed Generation Development Schedule	276
Table 8-8 — State Summary for Indiana CHP Installations	282
Table 8-9 — Microgrid Market Growth Projection	288
Table 8-10 — Microgrid Market Strategies	289



TABLES AND FIGURES (cont.)

<u>Table or Figure</u>	<u>Page</u>
Figure 3-1 — Indiana Nonattainment Area Designations	38
Figure 4-1 — Simple-Cycle Gas Turbine Development Cumulative Cash Flows	105
Figure 4-2 — Combined-Cycle Gas Turbine Development Cumulative Cash Flows	120
Figure 4-3 — Typical Natural Gas Cyclone Burner Arrangement	128
Figure 4-4 — Typical Natural Gas Wall Fired Burner	129
Figure 4-5 — Typical Tangentially Fired Natural Gas Burner Arrangement	130
Figure 4-6 — Coal-to-Gas Conversion Development Cumulative Cash Flows	143
Figure 5-1 — Coal Development Cumulative Cash Flows.....	156
Figure 5-2 — IGCC Development Cumulative Cash Flows.....	169
Figure 5-3 — Proposed New Nuclear Power Plants	173
Figure 5-4 — Nuclear Development Cumulative Cash Flows.....	185
Figure 6-1 — Biomass Development Cumulative Cash Flows	196
Figure 6-2 — Annual Wind Energy Capacity Installation in Indiana.....	198
Figure 6-3 — Indiana Wind Resource Map at 100 m	201
Figure 6-4 — Average Turbine Size for Historic Global and Planned U.S. Offshore Wind	204
Figure 6-5 — Indiana Offshore Wind Resource Map at 90 m	205
Figure 6-6 — U.S. Offshore Wind Forecast	206
Figure 6-7 — Wind Technology Development Cumulative Cash Flows	213
Figure 6-8 — Concentrated Solar Power Insolation Values	217
Figure 6-9 — Photovoltaic Solar Power Resource Values	219
Figure 6-10 — Solar PV Technology Development Cumulative Cash Flows.....	226
Figure 6-11 — Geothermal Power Generation Current and Nameplate Capacity in MW by State.....	229
Figure 6-12 — Geothermal Resource Favorability and Identified Systems	230
Figure 7-1 — Licensed Pumped Storage Projects	232
Figure 7-2 — Preliminary Permits for Pumped Storage Projects	233
Figure 7-3 — Topographic Map of Indiana	235
Figure 7-4 — Compressed Air Energy Storage Illustration.....	237
Figure 7-5 — Indiana Bedrock Map	239
Figure 7-6 — Underground Natural Gas Storage Facilities, by Type.....	240



TABLES AND FIGURES (cont.)

<u>Table or Figure</u>	<u>Page</u>
Figure 7-7 — Positioning of Energy Storage Technologies	242
Figure 7-8 — Battery Storage Technology Development.....	243
Figure 7-9 — Percentage of Battery Storage Technologies Deployed	244
Figure 7-10 — Battery Storage Development Cumulative Cash Flows	251
Figure 8-1 — NIPSCO FIT Program Breakdown by Location and Technology	254
Figure 8-2 — Small Scale Reciprocating Engine	255
Figure 8-3 — Reciprocating Engine Part Load Performance	257
Figure 8-4 — Compact Microturbine Design	258
Figure 8-5 — Summary of Microturbine Attributes	260
Figure 8-6 — Microturbine Part Load Performance	261
Figure 8-7 — Impact of Ambient Temperature on Microturbine Performance	261
Figure 8-8 — Impact of Elevation on Microturbine Performance	262
Figure 8-9 — Fuel Cell Illustration.....	263
Figure 8-10 — Characteristics of Major Fuel Cell Types.....	264
Figure 8-11 — Distributed Generation Development Cumulative Cash Flows.....	276
Figure 8-12 — Prime Mover with Heat Recovery Unit.....	279
Figure 8-13 — Steam Boiler with Steam Turbine	279
Figure 8-14 — CHP Efficiency Benefits	280
Figure 8-15 — U.S. Electricity Prices.....	282
Figure 8-16 — Microgrid Illustration	286
Figure 9-1 — Effect of DG on Short Circuit Current in Same Feeder.....	296
Figure 9-2 — Effect of DG on Short Circuit Current in Parallel Feeder	297
Figure 9-3 — Incorrect Operation of Fuses	298
Figure 9-4 — Energy Management System Illustration	304



ACRONYMS AND ABBREVIATIONS

Term	Definition or Clarification
ACI	Activated Carbon Injection
AFUDC	Allowance for Funds Used During Construction
AMSL	Above mean sea level
APWR	Advanced pressurized water reactor
ASU	Air separator unit
BACT	Best available control technology
BLS	Bureau of Labor Statistics
BOP	Balance of plant
C&I	Commercial and industrial
CAA	Clean Air Act
CAES	Compressed air energy storage
CC	Combined cycle
CCHP	Combined Cooling, Heat and Power
CCS	Carbon capture and sequestration
CHP	Combined heat and power
CO	Carbon monoxide
CSP	Concentrated solar power
CT	Combustion turbine
CTG	Combustion turbine generator
CWA	Clean Water Act
DBB	Design-Bid-Build
DG	Distributed generation
DLN	Dry-low NOx combustion
DOE	Department of Energy
DSI	Dry sorbent injection
DSIRE	Database of State Incentives for Renewables & Efficiency [®]
EAF	Equivalent availability factor
EFOR	Equivalent forced outage rate
EGU	Electric generating unit



ACRONYMS AND ABBREVIATIONS (cont.)

Term	Definition or Clarification
EIA	Energy Information Administration
EPA	Environmental Protection Agency
EPC	Engineer, procure, and construct
EPRI	Electric Power Research Institute
ERC	Emission reduction credits
ESP	Electrostatic precipitator
FERC	Federal Energy Regulatory Commission
FF	Fabric filter
FGD	Flue gas desulfurization
FICA	Federal Insurance Contributions Act
FIT	Feed-in tariff
FOH	Forced outage hours
FPM	Filterable particulate matter
GE	General Electric
GHG	Greenhouse gas
HAP	Hazardous air pollutant
HCl	Hydrogen chloride
Hg	Mercury
HHV	Higher heating value
hp	Horsepower
HRSG	Heat recovery steam generator
HVAC	Heating, Ventilation, & Air Conditioning
Hz	Hertz
IAC	Indiana Administrative Code
ICI	Industrial-Commercial-Institutional
IDEM	Indiana Department of Environmental Management
IDNR	Indiana Department of Natural Resources
IGCC	Integrated gasification combined cycle
IRP	Integrated resource plan



ACRONYMS AND ABBREVIATIONS (cont.)

Term	Definition or Clarification
kW	kilowatt
LAER	Lowest achievable emissions rate
LAES	Liquefied air energy storage
LNB	Low NO _x burners
MACT	Maximum Achievable Control Technology
MATS	Mercury and Air Toxics Standards
MGD	Million gallons per day
mmBtu	Millions of Btu
MW	Megawatt
MWh	Megawatt-hour
MYRD&D	Multi-Year Research, Development, and Demonstration
NAAQS	National Ambient Air Quality Standards
NESHAP	National Emissions Standards for Hazardous Air Pollutants
NNSR	Non-attainment New Source Review
NOWS	National Offshore Wind Strategy
NO _x	Nitric oxide (NO) and nitrogen dioxide (NO ₂)
NPDES	National Pollutant Discharge Elimination System
NRC	Nuclear Regulatory Commission
NREL	National Renewable Energy Laboratory
NSCR	Non-selective catalytic reduction
NSPS	New Source Performance Standards
NSR	New Source Review
O&M	Operation and maintenance
O ₂	Oxygen
OFA	Overfire air
OSWInD	Offshore Wind Innovation and Demonstration Initiative
PAS	Personnel Administration Services
Pb	Lead
PC	Pulverized coal



ACRONYMS AND ABBREVIATIONS (cont.)

Term	Definition or Clarification
PCB	Polychlorinated biphenyls
PH	Period hours
PILOT	Payments in lieu of taxes
PJFF	Pulse jet fabric filter
PM	Particulate matter
PM ₁₀	Particulate matter less than 10 micrometers
PM _{2.5}	Particulate matter less than 2.5 micrometers
ppbvd	Parts per billion volume dry
ppmvd	Parts per million volume dry
PSD	Prevention of Significant Deterioration
PV	Photovoltaic
R&D	Research and development
RBLC	RACT/BACT/LAER Clearinghouse
RFP	Request for proposal
RH	Relative Humidity
rpm	Revolutions per minute
S&L	Sargent & Lundy LLC
SCR	Selective catalytic reduction
SGC	Syngas cleanup
SHP	Separate Heat and Power
SIP	State Implementation Plan
SMR	Small modular reactor
SNCR	Selective non-catalytic reduction
SO ₂	Sulfur dioxide
SOH	Schedule outage hours
SPRINT	Spray inter-cooled
ST	Steam turbine
STG	Steam turbine generator
Syngas	Synthesis gas



ACRONYMS AND ABBREVIATIONS (cont.)

Term	Definition or Clarification
T&D	Transmission and distribution
TES	Thermal energy storage
tpy	Tons per year
USDA	United States Department of Agriculture
USGS	United States Geological Survey
VOC	Volatile organic carbon
VOM	Variable O&M
WFGD	Wet Flue gas desulfurization
WTG	Wind-turbine generator

Last page of front matter.



1. EXECUTIVE SUMMARY

1.1 PROJECT INTRODUCTION

To support development of its 2016 IRP, The Northern Indiana Public Service Company (NIPSCO) engaged Sargent & Lundy LLC (S&L) to conduct a technical assessment of various generation technologies reflective of a Northern Indiana location. The list of technologies considered in the study was discussed during the project kick-off meeting and includes the technical options that might be considered feasible for the NIPSCO service territory and other options that are of interest to the utility, regulators, and stakeholders.

This technology assessment study includes an evaluation of the following technologies:

- Natural Gas Technologies – Section 4
 - Simple Cycle Aeroderivative Combustion Turbine (50 MW)
 - Simple Cycle Frame Combustion Turbine (240 MW)
 - Combined Cycle Frame Combustion Turbines (700 MW)
 - Combined Cycle Bailly Unit 7 Repowering (Coal to Combined Cycle Conversion)
 - Combined Cycle Schahfer 16A/B Conversion (2 Simple Cycle Frames to Combined Cycle)
 - Combined Cycle Generic Conversion (2 Simple Cycle Frames to Combined Cycle)
 - Black Start Retrofit at Schahfer Unit 16B
 - Coal to Natural Gas Boiler Conversion at Schahfer Unit 14
 - Coal to Natural Gas Boiler Conversion at Schahfer Unit 15
 - Coal to Natural Gas Boiler Conversion at Schahfer Unit 17 and 18
 - Coal to Natural Gas Boiler Conversion at Schahfer Unit 14, 15, 17, and 18 Collectively
- Coal and Nuclear Technologies – Section 5
 - Supercritical Pulverized Coal (750 MW gross)
 - Circulating Fluidized Bed Coal with Fuel Flexibility (400 MW gross)
 - Integrated Gasification Combined Cycle (600 MW gross)
 - Advanced Pressurized Water Reactor (2200 MW)
 - Small Modular Reactor (45 MW)
- Renewable Technologies – Section 6
 - Bubbling Fluidized Bed Biomass Boiler (50 MW)
 - Onshore Wind (100 MW)
 - Offshore Wind (50 MW)



- Concentrated Solar Power (50 MW)
- Utility Scale Solar Photovoltaic (50 MW)
- Geothermal (5 MW)
- Energy Storage Technologies – Section 7
 - Pumped Storage
 - Thermal Storage
 - Compressed Air Storage
 - Liquefied Air Storage
 - Battery Storage
- Distributed Generation Technologies – Section 8
 - Reciprocating Engine Firing Biogas and/or Conventional Fuel Supply
 - Microturbines
 - Fuel Cells
 - Distributed Solar PV
 - Distributed Wind
 - Combined Heat and Power
 - Microgrids
- Grid Reliability Enhancements – Section 9
 - Interconnection Upgrades for Distributed Generation
 - Volt/VAR Optimization and Sensors

The assessment includes a review of the environmental requirements that apply to each generating technology to identify specific emission control technologies, for which cost, performance, and emissions data was developed. For the conventional technologies (i.e. natural gas, coal, and nuclear), the types of alternatives are well-known, and therefore, NIPSCO identified the specific configurations to consider. For renewable energy, energy storage, and distributed generation, a more extensive distributed generation screening analysis was performed to identify the commercially available technologies and the emerging technologies seen throughout the power industry. The complete distributed generation screening analysis is attached to this report as Appendix A. Throughout the remainder of this report, S&L presents the estimated cost, performance, and emissions data for both the conventional technologies and selected distributed generation technologies as well as the methodology and assumptions underlying these estimates.